

**Kentucky**  
**Agricultural Experiment Station**

**University of Kentucky**

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**The Effect of Soil Reaction on the Growth of Tomatoes  
and Lettuce and on the Nitrogen, Phosphorus and  
Manganese Content of the Soil and Plant.**

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**BULLETIN NO. 314.**

**(RESEARCH BULLETIN)**

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**Lexington, Ky.**

**March, 1931**

**(1)**

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## SUMMARY

1. Tomatoes and lettuce were grown in soil adjusted to different reactions, from pH 4.4 to pH 9.8, by the addition of phosphoric acid, sulfuric acid, nitric acid, calcium carbonate, calcium hydroxide or sodium carbonate.

2. The soil reaction seemed not to influence the growth and yield of tomatoes and lettuce directly, but rather by affecting nutrient relationships and toxicity of soil constituents.

3. Acidity between pH 4.3 and pH 5.3 increased the early yield of tomatoes, but the total yield was less than that of the checks. The data indicate that nitrate nitrogen was a limiting factor in these plots.

4. Alkaline reaction increased the yield of tomatoes. With sodium carbonate to pH 8.3 to 8.5, the increase was very marked. It was not so marked with lime to the same reaction.

5. Sodium carbonate to produce pH 7.2 to 8.6, increased the yield of lettuce greatly, but at pH 8.6 to 8.9 or with lime to pH 8.3 to 9.8, the yield was only slightly larger than that of the checks.

6. Lime without organic matter caused poor growth and yellow foliage of both lettuce and tomatoes. The phosphate content of the plants was diminished.

7. Acidity of pH 5.6 to 5.4 with phosphoric acid, or pH 6.5 to 6.0 with sulfuric acid, produced a marked increase in the yield of lettuce.

8. Both tomatoes and lettuce exhibited exceptional vigor of growth on certain of the alkaline plots, especially where organic matter had been added. This is attributed to increased nitrification and azofication brought about by the alkali.

9. Application of sodium carbonate and organic matter, perhaps supplemented by lime, offers a method of increasing soil fertility without the use of legumes and without the danger of precipitating certain elements as is the case when lime alone is used.

10. When the acidity of the manganiferous bluegrass soil is made stronger than pH 6, by either phosphoric, nitric or sulfuric acid, manganese is made soluble. The rapid increase of the quantity dissolved, with increased acidity, suggests that toxic concentration may easily be reached.

11. Analysis for nutrient elements in the conducting tissue of a plant seems to afford better evidence of what the plant can obtain from the soil, than analysis of the soil in which the plant is growing.



## CONTENTS

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|                                                                                   | Page |
|-----------------------------------------------------------------------------------|------|
| Literature review .....                                                           | 5    |
| Experimental procedures .....                                                     | 11   |
| Control of insects and diseases .....                                             | 18   |
| Methods of analysis of the soil .....                                             | 19   |
| Methods of analysis of the plant .....                                            | 21   |
| Reactions obtained in the soil .....                                              | 21   |
| Yields of tomatoes and lettuce .....                                              | 23   |
| Nitrate nitrogen in the soil .....                                                | 25   |
| Nitrate nitrogen in tomato and lettuce tissues .....                              | 28   |
| Total nitrogen in tomato and lettuce tissues .....                                | 30   |
| Total nitrogen in the soil .....                                                  | 31   |
| Filterable phosphorus in the soil and phosphate phosphorus in<br>the plant .....  | 33   |
| Total phosphorus in tomato and lettuce tissues.....                               | 35   |
| Filterable manganese in the soil and total in tomato and lettuce<br>tissues ..... | 36   |
| Discussion of results .....                                                       | 37   |
| Yield of lettuce .....                                                            | 45   |
| Yield of tomatoes .....                                                           | 46   |
| Nitrate nitrogen in the plant .....                                               | 47   |
| Total nitrogen in the plant.....                                                  | 49   |
| Phosphate phosphorus and total phosphorus in the plant.....                       | 50   |
| Manganese in the plant.....                                                       | 51   |
| Correlations .....                                                                | 52   |
| Other effects of controlled soil reaction.....                                    | 62   |
| Conclusions .....                                                                 | 64   |
| Literature cited .....                                                            | 70   |

## BULLETIN NO. 314.

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### The Effect of Soil Reaction on the Growth of Tomatoes and Lettuce and on the Nitrogen, Phosphorus and Manganese Content of the Soil and Plant.

By E. M. EMMERT.\*

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The purpose of this investigation was to determine what effect varying the reaction of a uniform soil by adding certain reagents, would have on the growth and yield of tomatoes and lettuce. Lime and other reagents were used in order to ascertain whether or not a certain pH is optimum for plant growth regardless of the reagent employed to produce the particular reaction. At the same time a study was made of the effect of the different reactions obtained and ions added on the transformations of nitrogen, phosphorus, and manganese compounds in the soil and their absorption by tomato and lettuce plants.

#### LITERATURE REVIEW

*Control of Soil Reaction.* In most of the experiments in the control of soil reaction, some form of sulfur has been used to increase acidity, and some form of lime to produce alkalinity. Joffe and McLean (48), Lipman and Sharp (56), Martin (59), Rudolfe (71), Blair and Prince (4), and Gainey (31) give examples of the use of forms of sulfur to create acidity. Acetic, hydrochloric, butyric, silicic, and phosphoric acids also were used in some of the experiments. Hoagland and Christie (45), Pierre (67), and Gainey (31) give examples of the use of different forms of lime in regulating soil reaction. Basic slag, magnesium carbonate, and sodium carbonate also were used.

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*Soil Reaction and Nitrification.* Cook (18), Barthel and Bengtsson (2), Robinson and Bullis (69), Noyes and Conner (64), H. D. Brown (9), P. E. Brown (10), Willis (82), Iowa Agricultural Experiment Station (46), Wohlbier (86), and Uspenskii (79) show that acidity decreases nitrification and that lime almost invariably increased nitrification, altho some point out that too great alkalinity may cause denitrification.

As yet little work has been done on the effect of sodium carbonate on nitrification. Greaves (38), Gibbs, Batchelor and Magnuson (33), and Brown and Hitchcock (11) found that moderate amounts of sodium carbonate stimulated both ammonification and nitrification and that sodium carbonate did not seem to be a factor in reducing crop yields.

A few investigators have endeavored to find the exact range and optimum pH for the nitrifying bacteria. The Iowa Station (46) reports complete cessation of nitrification at pH 4.2. Olsen (65) working with calcium oxide on acid humus soils, set the range at pH 3.7-8.8, with the optimum at pH 8.3. Gowda (36) stated that the optimum for nitrate formers is pH 8.5-8.8. Gaarder and Hagen (30) found the limiting acidity to be pH 4.0-4.4, while the optimum pH was 6.8-7.3. Winogradsky (84), in 1904, recognized that nitrobacter thrived best in an alkaline medium, since the two main salts in his medium for nitrobacter, sodium nitrite and sodium carbonate, are highly alkaline.

*Soil Reaction and Nonsymbiotic Nitrogen Fixation.* Most of the work on nonsymbiotic nitrogen fixation has been done with cultures in the laboratory, and most of the literature on the subject is directly concerned with *Azotobacter*. Recent literature, however, has been crediting other organisms with almost as much importance as *Azotobacter*. In fact Carter and Greaves (17) claim that Utah soils are extremely active in fixing nitrogen without *Azotobacter* being present. They describe 26 organisms which fix nitrogen in Utah soils, some quite actively, the majority of these being actinomyces. These soils are high in potassium and in magnesium and calcium carbonates.

Gainey (32), in a study of the effect of the reaction of the



soil on *Azotobacter*, found pH 6.0 to be the limit of acidity for the presence of *Azotobacter*. In soils from pH 6.0 to pH 7.6 *Azotobacter* thrived. The Kansas Agricultural Experiment Station (51) reports that *Azotobacter* disappeared from unlimed soils regardless of food supply, even when sugar was applied. In all well-limed soils *Azotobacter* were present. Krishna (54) found a direct correlation between the fixation of nitrogen in soils and their reactions, within the range from pH 5.22 to pH 7.65. He states that 3.0 mg. of nitrogen were fixed by soils with reactions from pH 5.2 to pH 5.9, whereas between 3.6 and 4.7 mg. were fixed in soils with reactions from pH 5.9 to 7.65. Gainey (31) noted that calcium carbonate caused an increase in *Azotobacter* growth and in the amount of nitrogen fixed. Sackett (72) reported that phosphates stimulated *Azotobacter* growth and nitrogen fixation. Besides adding phosphorus, phosphates usually led to a high pH. Yamagata and Itano (87) show optimum hydrogen ion concentration for the *Azotobacter* species to vary between pH 6.7 and 7.7. The acid limit is pH 5.9. Johnson and Lipman (49) obtained considerable nitrogen fixation at pH 8.8. The optimum, however, was between pH 7.0 and 8.0. Krishna (55) found the optimum range of pH. for *B. amylobacter* to be 6.0 to 7.0, while *Azotobacter* thrived best at 7.0 to 8.4. Much dextrose in the medium produced too much acid.

Winters (85) emphasized the need for plenty of organic matter with an almost neutral or alkaline medium, in the fixation of nitrogen. In laboratory cultures, with 0.1, 0.4, and 1 percent of limestone added to a soil, he obtained the equivalent of 52, 644, and 560 pounds per acre of nitrogen fixed, respectively. With large applications of rotted horse manure, the equivalent of 1168 pounds of nitrogen were fixed and with 1.5 percent of pea vines, 996 pounds. Limestone and quicklime, added in equivalent quantities of calcium, had about the same effect on nitrogen fixation. Dolomitic limestone was better than calcitic limestone.

Greaves (37, 38), studying the effect of leaching and certain microbial stimulants on the fixation of nitrogen, found that

sodium carbonate and arsenite caused greater development of colonies of bacteria than did 15 tons of manure per acre. He showed that 2 percent of sodium carbonate was toxic, but 1 percent caused a larger gain in total nitrogen than any other salt used alone. Organic matter was quite efficient in causing azofication, 911 pounds of nitrogen per acre being added from the air, in 3 years, in one experiment. Greaves attributes these results to the inhibition caused by stimulants of a "bacteriophagic substance ultramicroscopic in size and having the characteristics of a virus or ferment". When the bacteriophage is repressed the nitrifiers become active.

Few investigations are on record in which asymbiotic fixation of nitrogen under field conditions was recorded. Wilsdon and Ali (83) present interesting data upon fixation in the field. Remarkably large fixation was observed in 1916, most of it following a wet season. Observations during the next four years, however, were inconclusive. They conclude that the time of sampling is important and that the soil does not become capable of considerable nitrogen fixation until after a prolonged period of dry, hot weather.

*Soil Reaction and Transformations of Phosphorous Compounds.* Most of the literature bearing on the transformations of phosphorous compounds in the soil deals with the composting of rock phosphate with sulfur or manure or treating with sulfuric acid. Brown and Gwinn (13), Tottingham and Hoffmann (77), Truog (78), and Bauer (3) find phosphorous is made more available by these treatments. Manure may decrease water soluble phosphorous but seems to increase availability to the plant despite this fact. Wiley and Gordon (81) and Roszmann (70) find fixation of phosphorous, especially in a calcium clay. Teakle (76) shows that phosphorous is freed from insoluble ferric phosphate by the precipitation of the hydroxide when a soil is made alkaline. The same is true to a less extent of aluminum and manganese phosphates. Fraps (28) shows fixation of phosphorous with increase in aluminum and iron but not of calcium. McGeorge (61) finds that lime increases phosphorous availability in certain soils high in iron. Ames and



Gaither (1), and Breazeale and Burgess (7) show that calcareous soils contain more available phosphorous than acid soils, particularly in the presence of iron and aluminum. Rock phosphate, however, was of value on acid soils but not on alkaline soils. Parker and Tidmore (66) show that the soil solution is very low in dissolved phosphorus. Lime varied in its effect. Magruder (57) shows reversion of phosphorous by lime.

*Soil Reaction and Transformations of Manganese Compounds.* Manganese can change valence easily and is either basic or acidic in property depending on the valence. This makes it hard to follow its changes in the soil. McHargue (62), Furchess (29), and Skinner and Reid (75) show that manganese is most active and often toxic in acid soils.

Brown and Minges (12) reported that manganese was especially deleterious to nitrification. Ammonification was not so greatly affected. This may be one reason why nitrate formation is low in acid soils, since it is apparent that manganese becomes active in acid soils. Carr and Havercamp (16) showed that the addition of acids to soil greatly increased the content of active manganese, as measured by the quantity of manganese taken up by buckwheat and soybeans grown in the soil. Gilbert, McLean, and Hardin (34), on the other hand, found a deficiency of managanese induced by continued addition of lime. Carr and Brewer (15) concluded that 75 pounds or more of soluble manganese per acre was toxic. It is difficult to completely precipitate manganese by lime or other alkali. The precipitation begins at pH 7.2 and is complete at about pH 8.0. Ferric iron comes out at pH 5.5; ferrous iron at pH 6-7.9; aluminum phosphate at pH 3.9; and aluminum hydroxide at pH 6. Aluminum hydroxide redissolves at pH 8.6.

*Soil Reaction and Yield of Lettuce.* Only four investigations were found in which attention was focused on the effect of soil reaction on lettuce. Hartwell and Damon (41), in 1914, found that lettuce was greatly favored by applications of lime. On the other hand, in 1925, Crist (19) noted very harmful effects from lime and proved lettuce to be quite acid tolerant. In 1927, Gourley (35) reported no deleterious effect of lime

on lettuce until a reaction of pH 8.5 was reached. At that point the leaves gave indications of some unfavorable condition, but below that point, lime usually proved beneficial. In 1928, Hardenburg (39), working with acid muck soils, found that in acid soils high in plant nutrients lettuce did not respond to liming. In fact he agreed with Crist, that lettuce is quite acid tolerant.

Evidently the problem is far from settled. Undoubtedly part of the reason for this division of opinion is that results were influenced by differences in the soils used. Hartwell and Damon were working with heavy clay soils containing much aluminum, iron, and manganese which were toxic in acid soil, and lime immediately overcame this toxicity. Crist was working with a mixture of two-thirds muck, one-third fairly coarse drift sand and a potting soil of a loamy nature, which did not contain such large amounts of toxic elements. Crist gave the amount of "active" aluminum found by Burgess and Pember's method as 0.104 percent. Burgess (14) working with soils from the same station as Hartwell and Damon (41), obtained about the same amount (841 p.p.m.). However, it is recognized that heavy clay soils usually contain more of the mineral elements which an acid reaction is likely to bring into "toxic activity". Burgess (14) found much "active" aluminum in acid soils and ascribed decreased yields of lettuce on the acid side to the "active" aluminum and the better yields on the alkaline side to the precipitation of this element. However, results reported later in this paper show that manganese may be even more potent in its toxic action in acid soils than is aluminum.

Again, in 1918, Hartwell and Pember (42) reported that lime, even in small quantity, greatly benefited lettuce. They ascribed the results to the decomposition of toxic aluminum sulfate. Opposed to this is the work of Boullanger (5) who found that applications of sulfur, aluminum sulfate, and manganese sulfate increased the yields of lettuce.

Sandsten (73) reported that animal manures were much superior to chemical manures on lettuce. Other similar reports

might be given of the beneficial effects of manure (which usually has an alkaline reaction) on the yields of lettuce.

Only one test of the effect of an application of sodium carbonate on lettuce was found in the literature and in this the carbonate was not applied to control the reaction. Wheeler (80) found that lettuce did much better with sodium carbonate than with sodium chloride, altho potassium carbonate was the best treatment of all.

*Soil Reaction and Yield of Tomatoes.* No definite study of the effect of soil reaction on the yield of tomatoes was found. A number of reports are given of the effects of liming, but no experiments were found in which carefully recorded or controlled soil reaction changes were tested.

In 1898, Jordan (50) stated that nitrate of soda in all trials gave the earliest yield but that lime caused a greater growth of vine. Massey (60), in 1900, obtained much greater yields from limed plots, due primarily to the control of bacterial blight. In 1914 Hartwell and Damon (41) noted no benefit from lime on tomatoes. In 1918 Montgomery (63) found that limestone with a complete fertilizer gave increases in the yield of tomatoes. Magruder (58) reported that lime alone increased the yield of tomatoes. Also, when used in combination with manure, the yield was increased, but when used with commercial fertilizers the phosphorous seemed to be locked up.

*Soil Reaction and the Nitrate, Phosphate, and Manganese Content of Plants.* No investigations were found which gave data on the effect of soil reaction on the nitrate, phosphate, or manganese absorption in tomatoes and lettuce. Gilbert, McLean and Hardin (34) found manganese starvation on highly limed soil, while iron was found abundant in oats and spinach. Carr and Havercamp (16) gave the only data found on the effect of acids on the amount of manganese in plants. Additions of sulfuric, silicic and acetic acids to soils increased the manganese content in soybeans. Phosphoric acid seemed to lower it somewhat.

#### EXPERIMENTAL PROCEDURES

*Choice of Medium.* Most investigators have used solution or sand cultures in their reaction experiments. Altho these



give better opportunity to control the reaction and to know the composition of the medium, they do not represent actual soil conditions. Results obtained in solution and sand cultures are often exactly opposite to those which would be obtained in soil. While all soils are not alike, it is obvious that results obtained in a soil would be more nearly applicable to other soils than would the results of solution cultures. Furthermore, the investigator using solution or sand cultures cannot follow all the changes taking place in his cultures even if he knows all the constituents of the medium. The results from the direct treatment of soils, obviously, are more practical and worth while even if all the complex phenomena taking place cannot be followed.

*Soil Reaction and the Nutrient Solution.* Reaction influences the chemical composition of the nutrient solution in the soil in two ways. First, by affecting the solubility of the minerals, and, second, by affecting the growth of the bacterial flora. The second way is indirect, in that the bacterial growth regulates to a large extent the amount of nutrients in the soil solution. However, the combined effects of the two influences may be ascertained by determining the composition of the solution in the soil. The reaction and various ions present also undoubtedly affect the physical make-up of the soil, and this influences both bacterial and plant growth. It is impossible to regulate the reaction of the soil unless some foreign ion is added, since the  $H^+$  and  $-OH$  ions cannot be added alone, but must be coupled to some electropositive or electronegative ion which may or may not affect the growth of plants.

*Reagents Used in Controlling the Soil Reaction.* In order to measure plant growth at a certain reaction, for example, pH 5, it would not be desirable merely to use sulfur or sulfuric acid in sufficient quantity to bring about a reaction of pH 5, because the sulfate radical may have a specific effect besides its effect on acidity. In order to overcome this difficulty at least partially, three different acids and three different bases were used in three different ways, to secure the various reactions

from pH 4 to pH 9. Sulfuric, phosphoric, and nitric acids were used as the acids and calcium carbonate, calcium hydroxide, and sodium carbonate, as the basic substances. If the plants grew best at pH 5 with all the acids used it would be reasonably safe to conclude that this was the best reaction for the growth of the plant in question.

*Choice of Crops.* Bonny Best and Marglobe tomatoes were used as typical of a deep-rooted warm-season crop. Grand Rapids forcing lettuce was used as typical of a shallow-rooted quick-growing, cool-season crop.

*Soil Used.* Soil was taken from the Experiment Station farm at Lexington, from a rather low place on the north central part of the area devoted to Horticulture. It was of an unusually black color for Kentucky bluegrass soil as found around Lexington. The soil was thoroly mixed with a well-rotted manure and sod compost in the ratio of about  $\frac{3}{4}$  soil to  $\frac{1}{4}$  compost, before being placed in the greenhouse benches.

*Treatment of the Soil.* Diagram 1 shows the arrangement and treatment of the plots on which lettuce was grown from October 21st, 1928 to April 8th, 1929. Since the greenhouse was too warm for lettuce, from April 14th to July 19th, 1929, tomatoes were grown on these plots during this period. Lettuce

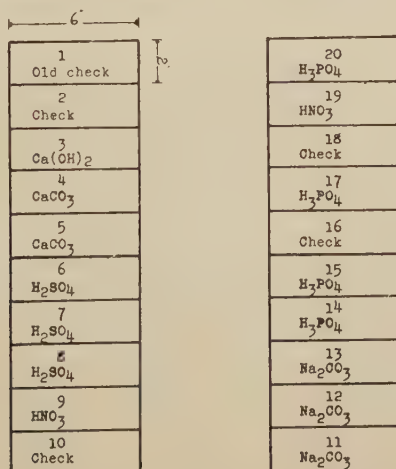


Diagram 1. Arrangement of the Lettuce Plots.

was again grown on the plots from October 1st, 1929, to February 12th, 1930. Table 1 shows the chemicals added. The same kind of soil was used for all the plots except numbers 1 and 20. From October 21st, 1928, to July 19th, 1929, an old soil which had been in the greenhouse for several years was used in plots 1 and 20. On September 26th, 1929, the old soil in plots 1 and 20 was discarded and a fresh soil of approximately the same source and like treatment as in the other plots was used in its place. On September 10th, 1929, 14 pounds of medium rotted cow manure were added to plots 4, 7, 8, 9, 10, 11, 13, 15, and 16. This was equivalent to an addition of 25 tons per acre.

TABLE 1. Treatments of Soil on Which Lettuce was Grown from October 20, 1928, to February 12, 1930.\* Grams Per Plot. (1000 gms. = 2.2 tons to 2 million pounds of soil.)

| Plot | Chemicals Used†                 | October 19, 1928 | November 2, 1928 | February 19, 1929 | Total Added for Lettuce 1928-29 | April 12, 1929      | September 26, 1929                   | Total Added                     |
|------|---------------------------------|------------------|------------------|-------------------|---------------------------------|---------------------|--------------------------------------|---------------------------------|
| 1    | Old Check                       |                  |                  |                   |                                 |                     | New Compost Check                    |                                 |
| 2    | Check                           |                  |                  |                   |                                 |                     |                                      |                                 |
| 3    | Ca(OH) <sub>2</sub>             | 1000             | 500              | 800               | 2300                            | 200                 | 500                                  | 3000                            |
| 4    | CaCO <sub>3</sub>               | 2000             | 3000             | 3000              | 8000                            | 100                 |                                      | 8000+                           |
|      |                                 |                  |                  |                   |                                 | Ca(OH) <sub>2</sub> |                                      | 100                             |
| 5    | CaCO <sub>3</sub>               | 1000             | 500              |                   | 1500                            |                     |                                      | Ca(OH) <sub>2</sub>             |
| 6    | H <sub>2</sub> SO <sub>4</sub>  | 100              | 100              | 200               | 400                             | 50                  | 200                                  | 1500                            |
| 7    | H <sub>2</sub> SO <sub>4</sub>  | 400              |                  | 400               | 800                             | 100                 | 300                                  | 650                             |
| 8    | H <sub>2</sub> SO <sub>4</sub>  | 800              | 300              | 700               | 1800                            | 200                 | 700                                  | 1200                            |
| 9    | HNO <sub>3</sub>                | 400              |                  | 500               | 900                             | 100                 | 300                                  | 2700                            |
| 10   | Check                           |                  |                  |                   |                                 |                     |                                      | 1300                            |
| 11   | Na <sub>2</sub> CO <sub>3</sub> | 600              | 100              | 200               | 900                             | 100                 | 400                                  |                                 |
| 12   | Na <sub>2</sub> CO <sub>3</sub> | 400              |                  |                   | 400                             | 50                  |                                      | 1400                            |
| 13   | Na <sub>2</sub> CO <sub>3</sub> | 200              |                  |                   | 200                             |                     |                                      | 450                             |
| 14   | H <sub>3</sub> PO <sub>4</sub>  | 150              |                  | 200               | 350                             | 100                 | 200                                  | 200                             |
| 15   | H <sub>3</sub> PO <sub>4</sub>  | 400              | 100              | 500               | 1000                            | 100                 | 500                                  | 650                             |
| 16   | Check                           |                  |                  |                   |                                 |                     |                                      | 1600                            |
| 17   | H <sub>3</sub> PO <sub>4</sub>  | 800              | 300              | 800               | 1900                            | 300                 | 1500                                 |                                 |
| 18   | Check                           |                  |                  |                   |                                 |                     |                                      | 3700                            |
| 19   | HNO <sub>3</sub>                | 100              |                  | 150               | 250                             |                     | 100                                  | 350                             |
| 20   | Old Soil                        | 70               |                  |                   | 70                              |                     | New Compost                          | 70+                             |
|      | H <sub>3</sub> PO <sub>4</sub>  |                  |                  |                   |                                 |                     | + 150 gm.                            | 150 gm.                         |
|      |                                 |                  |                  |                   |                                 |                     | gms. Na <sub>2</sub> CO <sub>3</sub> | Na <sub>2</sub> CO <sub>3</sub> |

\*Tomatoes were grown on these plots from April 14 to July 19, 1929.

†On Sept. 10, 1929, manure was added to plots 4, 7, to 11, 13, 15, and 16.



The chemicals added were sodium carbonate ( $\text{Na}_2\text{CO}_3$ , anhydrous powder), hydrated lime ( $\text{Ca}(\text{OH})_2$ ), commercial powder), limestone ground to pass about a 10-mesh sieve, to supply calcium carbonate ( $\text{CaCO}_3$ ), sulfuric acid ( $\text{H}_2\text{SO}_4$ , concentrated, c. p.), phosphoric acid ( $\text{H}_3\text{PO}_4$ , 85 percent syrupy U. S. P.), and nitric acid ( $\text{HNO}_3$ , concentrated c. p.).

Diagram 2 shows the arrangement and treatments of the plots in which tomatoes were grown from October 20, 1928, to July 19, 1929, and September 16, 1929, to February 1, 1930. Table 2 shows the chemicals added. The soil in plots 1 and 33 was changed just as in the lettuce plots, numbers 1 and 20. On September 10, 1929, manure was added to plots 17 to 33, inclusive, at the same rate as on the lettuce plots. The chem-

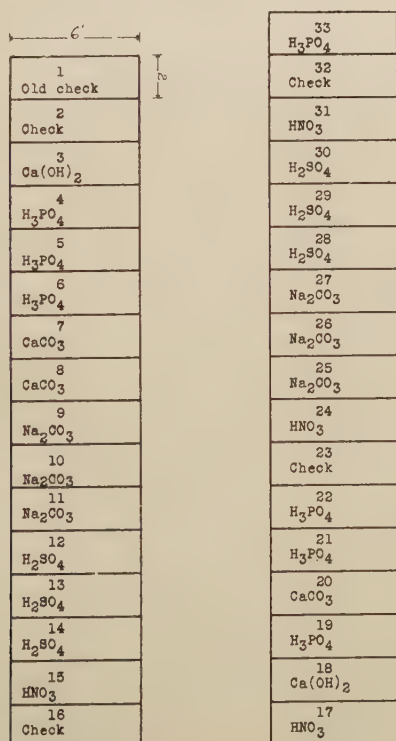


Diagram 2. Arrangement of the Tomato Plots.

icals used were taken from the same containers as those used on the lettuce plots. The soil used has been described.

*Quantity of Reagent Needed.* In order to determine the quantities of reagents needed, 20-gram portions of the soil to be used were treated with varying quantities of the reagents. Tenth normal solutions of the acids were used and the basic substances were applied in the solid form. The treated portions

TABLE 2. Treatments of Soil in Which Tomatoes Were Grown From October 20, 1928, to February 1, 1930. Grams Per Plot. (1000 gms. = 2.2 tons per million pounds of soil.)

| Plot | Chemicals Used*                 | October 16, 1928 | November 2, 1928 | Total on Fall Crop | Total on Spring Crop Feb. 1929 | September 13, 1929                                | Total Chemicals Added                    |
|------|---------------------------------|------------------|------------------|--------------------|--------------------------------|---------------------------------------------------|------------------------------------------|
| 1    | Old                             |                  |                  |                    |                                | New Compost                                       |                                          |
| 2    | Check                           |                  |                  |                    |                                |                                                   |                                          |
| 3    | Ca(OH) <sub>2</sub>             | 200              | 1000             | 1200               | 800                            | 500                                               | 2500                                     |
| 4    | H <sub>3</sub> PO <sub>4</sub>  | 35               |                  | 35                 | 200                            | 200                                               | 435                                      |
| 5    | H <sub>3</sub> PO <sub>4</sub>  | 135              | 800              | 935                | 500                            | 500                                               | 1935                                     |
| 6    | H <sub>3</sub> PO <sub>4</sub>  | 270              | 1000             | 1270               | 800                            | 1200                                              | 3270                                     |
| 7    | CaCO <sub>3</sub>               | 500              | 5000             | 5500               | 3000                           |                                                   | 8500                                     |
| 8    | CaCO <sub>3</sub>               | 200              | 2000             | 2200               |                                | 500                                               | 2200 + 500                               |
|      |                                 |                  |                  |                    |                                | Ca(OH) <sub>2</sub>                               | Ca(OH) <sub>2</sub>                      |
| 9    | Na <sub>2</sub> CO <sub>3</sub> | 300              | 100              | 400                | 200                            | 500                                               | 1100                                     |
| 10   | Na <sub>2</sub> CO <sub>3</sub> | 200              | 100              | 300                |                                |                                                   | 300                                      |
| 11   | Na <sub>2</sub> CO <sub>3</sub> | 100              |                  | 100                |                                |                                                   | 100                                      |
| 12   | H <sub>2</sub> SO <sub>4</sub>  | 25               | 100              | 125                | 200                            | 150                                               | 475                                      |
| 13   | H <sub>2</sub> SO <sub>4</sub>  | 100              | 400              | 500                | 500                            | 300                                               | 1300                                     |
| 14   | H <sub>2</sub> SO <sub>4</sub>  | 200              | 600              | 800                | 700                            | 700                                               | 2200                                     |
| 15   | HNO <sub>3</sub>                | 25               | 100              | 125                | 100                            | 100                                               | 325                                      |
| 16   | Check                           |                  |                  |                    |                                |                                                   |                                          |
| 17   | HNO <sub>3</sub>                | 100              | 150              | 250                | 500                            | 500                                               | 1250                                     |
| 18   | Ca(OH) <sub>2</sub>             | 200              | 1000             | 1200               | 800                            | 500                                               | 2500                                     |
| 19   | H <sub>3</sub> PO <sub>4</sub>  | 270              | 1000             | 1270               | 800                            | 1500                                              | 3570                                     |
| 20   | CaCO <sub>3</sub>               | 300              | 5000             | 5300               | 3000                           | 500                                               | 8300 + 500                               |
|      |                                 |                  |                  |                    |                                | Ca(OH) <sub>2</sub>                               | Ca(OH) <sub>2</sub>                      |
| 21   | H <sub>3</sub> PO <sub>4</sub>  | 135              | 800              | 935                | 500                            | 200                                               | 1635                                     |
| 22   | H <sub>3</sub> PO <sub>4</sub>  | 35               | 50               | 85                 | 200                            | 100                                               | 385                                      |
| 23   | Check                           |                  |                  |                    |                                |                                                   |                                          |
| 24   | HNO <sub>3</sub>                | 25               | 100              | 125                | 100                            | 100                                               | 325                                      |
| 25   | Na <sub>2</sub> CO <sub>3</sub> | 300              | 100              | 400                | 200                            | 500                                               | 1100                                     |
| 26   | Na <sub>2</sub> CO <sub>3</sub> | 200              | 50               | 250                |                                | 100                                               | 350                                      |
| 27   | Na <sub>2</sub> CO <sub>3</sub> | 100              |                  | 100                |                                |                                                   | 100                                      |
| 28   | H <sub>2</sub> SO <sub>4</sub>  | 200              | 600              | 800                | 700                            | 500                                               | 2000                                     |
| 29   | H <sub>2</sub> SO <sub>4</sub>  | 100              | 400              | 500                | 500                            | 100                                               | 1100                                     |
| 30   | H <sub>2</sub> SO <sub>4</sub>  | 25               | 50               | 75                 | 200                            | 50                                                | 325                                      |
| 31   | HNO <sub>3</sub>                | 100              | 100              | 200                | 500                            | 400                                               | 1100                                     |
| 32   | Check                           |                  |                  |                    |                                |                                                   |                                          |
| 33   | H <sub>3</sub> PO <sub>4</sub>  | 50               |                  | 50                 |                                | New Compost + 500 Na <sub>2</sub> CO <sub>3</sub> | 50 + 500 Na <sub>2</sub> CO <sub>3</sub> |

\*On Sept. 10, 1929, manure was added to plots 17 to 33, inclusive.

of soil were then saturated with water. In about one hour the pH was determined. The volume of soil in each plot was calculated and the approximate amount of reagent needed was calculated from the results of the preliminary tests.

*Method of Applying the Reagents.* The weighed quantity of the acid to be applied was put into a 6-liter Pyrex flask and the flask filled with water. After mixing, the solution was poured as uniformly as possible over the medium dry soil (approximately 10% moisture) in the plot. The soil was then soaked at once with water from a hose to dilute the acid still more and distribute it thru the soil. The basic substances were applied in the powdered or ground form and worked into the total eight inches of soil. The plots were then soaked with water. Several days were allowed before taking the pH reading, in order to permit the soil to come to equilibrium and excess water to drain out. If the reading indicated that further additions were needed the process was repeated. About three days after the last application of reagents the plants were set in the plots.

*Hydrogen Ion Determination.* Portions from four sections of the plot were composited and 20 grams of this soil shaken with 40 cc. of distilled water. The pH of this mixture was immediately determined by means of the quinhydrone electrode. The instrument used was a small, compact potentiometer designed especially for pH measurements with the quinhydrone electrode. The instrument is guaranteed accurate to 0.04 pH over a range of about pH 1 to pH 9. It is used in conjunction with a saturated calomel cell and a quinhydrone electrode, using gold coils as the electrode unit. The soils were shaken continuously by hand while the reading was being taken. The set was checked against a commercial standard buffer solution at the start of every set of determinations. The calomel electrode arm was flushed out after each reading.

Karraker (52) found that acid soils of Kentucky often cause a drift in the potential when quinhydrone is added to the soil, making the results unreliable. He states that this is probably due to the high manganese content of Kentucky soils.



However, fairly accurate results may be secured by taking the first reading. The soil used in this experiment was almost black, due to the presence of much organic matter. Little drift was found even in the acid soil, altho at times it became apparent in the extreme acid range.<sup>1</sup>

*Determining the Yields of Lettuce.* Before taking yields the plots were allowed to dry so that the foliage was in a normal condition as to moisture. The plants were cut off on a level with the ground. The yellowed or soiled leaves were broken off and the plants weighed immediately. The refuse was weighed and called unsalable. The total yields given in the tables include both the salable and unsalable portions of the plants. A record was taken of the dwarfed plants in some plots in order to determine the unevenness.

*Determining the Yields of Tomatoes.* The ripe fruits from each plot were weighed and the number taken. Dates of picking were recorded. At the end of the test any large, green tomatoes yet on the vines were recorded and their weight added to the total weight of ripe fruit. All sizes of fruit, but no fruit with serious blossom end rot, are included in the total yields given.

#### CONTROL OF INSECTS AND DISEASES

The first crop of tomatoes was injured badly by nematodes. After trying the usual methods of steam and chemical sterilization, with only partial success, a new method (23) was used successfully. The procedure was to close the greenhouse tightly, on a hot, sunny day in August, and fire the furnace to capacity. A temperature of 140-170 degrees F. was maintained for two days and nights. After this treatment, no trouble from nematodes was experienced in the second and third crops of tomatoes.

White fly was controlled by the use of pyrethrum sprays (24) under high pressure, applied when the greenhouse temperature was about 100 degrees F.

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<sup>1</sup> On soils from the Iowa Agricultural Experiment Station no drift whatever was found. The Iowa soils were low in manganese and high in organic matter.

*Fusarium* wilt caused some trouble when Bonny Best was used, but this was avoided almost entirely by using Marglobe.

Blossom end rot occurred, but no remedy was found.

Some tip burn was observed in the lettuce, but was not serious at any time, most of the crops being entirely free from it.

Aphis on the lettuce was controlled by tobacco fumigation.

#### METHODS FOR ANALYSIS OF THE SOIL

*Nitrate Nitrogen.* Samples were taken immediately before and after the growth of practically every crop of lettuce and of every crop of tomatoes, sometimes more frequently. The determinations after one crop served for those before the next crop when the succeeding crop was planted immediately. Soil was taken from 3 or 4 different places in each plot and mixed. These samples were immediately spread out in a thin layer and dried. Twenty-five grams of the composited air-dried soil were then shaken intermittently with 120 cc. of water and 5 cc. of half-molar copper sulfate solution, for about twenty minutes. One-half gram of calcium hydroxide was added, the mixture shaken for a few minutes, and filtered. A clear filtrate was obtained even with the extremes of pH, 4 and 9. The nitrate nitrogen in this filtrate was determined by the phenoldisulfonic acid method as described by Harper (40), except that the evaporation was carried out in 250 cc. Erlenmeyer flasks and sodium hydroxide was used as the base. A little more than 2 cc. of the phenoldisulfonic acid was used when needed to cover the salts in the flask.

*Total Nitrogen.* Portions from the samples prepared for the determination of nitrate were used for analysis by the chlorate method (20, 21). In this the nitrogen is oxidized to nitric acid, the nitric acid distilled off, chloride thrown out by silver sulfate, the distillate neutralized with calcium hydroxide, and nitrate nitrogen determined by the phenoldisulfonic acid method. This method was used instead of the official method primarily because the time for the determination was shortened to within an hour, and the procedure was much easier. Besides

the colorimetric method permitted the detection of smaller differences than the titration method. This is particularly true in small samples containing a small amount of nitrogen. The chlorate method was compared with the Kjeldahl method before accepting the results from it. The comparison was satisfactory (20).

*Total and Filterable Phosphorus.* These were determined by the use of sodium chlorate and an adaptation of Fiske and Subbarow's colorimetric method (22). The methods were found to be both rapid and accurate. The samples were taken as described for nitrate nitrogen.

When N/5 nitric acid (74) was tried on the soils treated to regulate pH it was found to bring all to approximately the same pH and to obscure differences due to the different reactions. The same would be true of other acid solvents. In order to obtain comparable results without introducing substances which might interfere, one part of the soil was shaken for ten minutes with two parts of water and allowed to stand a few minutes until the main mass of soil had settled. The supernatant liquid was then filtered thru a Whatman No. 2 filter paper. The filtrate contained water-soluble phosphorus and some phosphorus in the very fine colloidal particles.

Phosphorus was determined in this liquid and termed "filterable phosphorus". This was taken as being available to the plant since any action of the plant in absorbing undissolved phosphorus is undoubtedly exerted on the fine colloidal particles. Shaking for ten minutes is sufficient to break up the soil films without producing unnatural effects such as would occur if the soil were shaken for a long time with a large amount of water. Results presented later show a very consistent correlation of the filterable phosphorus with soil treatments and content of phosphate phosphorus in the plant. Samples for determination were taken as described for the nitrate nitrogen determinations.

*Total and Filterable Manganese.* These were determined by the use of sodium chlorate and an adaptation of both the official and Willard and Greathouse periodate methods for manganese (22). The extraction of the manganese was accomplished in



a similar way to that of total and filterable phosphorus. Samples were taken as for nitrate nitrogen.

#### METHODS FOR ANALYSIS OF THE PLANT

*Nitrate Nitrogen.* This was determined by grinding the green sample with calcium hydroxide, adding a solution of copper sulfate, filtering and determining nitrate in the filtrate by the phenoldisulfonic acid method (25).

*Total Nitrogen.* This was determined in one-gram green samples in the same manner as for total nitrogen in soil.

*Phosphate Phosphorus and Total Phosphorus.* Phosphate phosphorus was determined by grinding the fresh tissue with phosphate-free charcoal, mixing with 1 percent by volume sulfuric acid, filtering and determining phosphate in the filtrate by an adaptation of the method of Fiske and Subbarow (26). Total phosphorus was determined as in soil except that the proportions of reagents to the sample were as follows: Sodium chlorate was added at the rate of 0.3 to 1.0 gram per gram of fresh tissue, or 3 to 5 grams per gram of dry tissue. The exact amount depends on the ease of oxidation of the sample. This may be tested in a preliminary experiment. Usually about half way between the limits given is satisfactory. Concentrated nitric acid was added at the rate of 0.5 cc. per gram of fresh tissue, or 5 cc. per gram of dry tissue. The oxidation takes place as with soils. The flame may have to be withdrawn intermittently if foaming is excessive. One to five grams of green tissue or 0.1 to 0.5 gram of dry tissue were used, depending on the amount of phosphorus present. Sometimes the solution from the determination of total nitrogen was used.

*Total Manganese.* From 25 to 50 grams of green tissue were treated as described for total phosphorus. Manganese was determined in the clear solution exactly as described for total manganese in soil.

#### REACTIONS OBTAINED IN THE SOIL

Tables 3 and 4 give the reactions obtained by the addition of the reagents indicated in Tables 1 and 2. The symbols used

TABLE 3. pH Values Obtained in the Lettuce Plots.

| Plot              | Crop 1 | Crop 2 | Crop 3 | Ave. for Crops 1, 2, 3 | Crop 4 | Crop 5 | Ave. for Crops 4 & 5 | Desired pH |
|-------------------|--------|--------|--------|------------------------|--------|--------|----------------------|------------|
| 1 O. & N. Ck      | 5.98   | 6.31   | 6.31   | 6.20                   | 5.63   | 5.97   | 5.80                 |            |
| 2 Ck              | 6.99   | 7.15   | 7.25   | 7.13                   | 6.83   | 6.89   | 6.86                 |            |
| 3 Ca <sub>1</sub> | 9.77   | 9.73   | 8.39   | 9.30                   | 8.27   | 8.41   | 8.34                 | 9.0        |
| 4 Ca              | 7.76   | 7.84   | 7.49   | 7.70                   | 7.72   | 7.97   | 7.84                 | 8.0        |
| 5 Ca              | 7.42   | 7.54   | 7.34   | 7.43                   | 7.26   | 7.37   | 7.31                 | 7.0        |
| 6 S               | 6.47   | 6.51   | 6.51   | 6.53                   | 6.34   | 5.95   | 6.14                 | 6.0        |
| 7 S               | 5.41   | 5.97   | 5.94   | 5.74                   | 5.72   | 5.50   | 5.61                 | 5.0        |
| 8 S               | 4.41   | 4.54   | 4.95   | 4.48                   | 4.74   | 4.55   | 4.64                 | 4.0        |
| 9 N               | 5.00   | 6.20   | 5.93   | 5.71                   | 6.00   | 5.77   | 5.98                 | 5.0        |
| 10 Ck             | 6.78   | 7.07   | 7.22   | 7.02                   | 6.85   | 6.95   | 6.90                 |            |
| 11 Na             | 8.74   | 8.89   | 8.85   | 8.83                   | 8.04   | 8.89   | 8.76                 | 9.0        |
| 12 Na             | 8.61   | 8.46   | 8.10   | 8.36                   | 7.67   | 7.73   | 7.70                 | 8.0        |
| 13 Na             | 8.31   | 8.59   | 7.79   | 8.23                   | 7.23   | 7.40   | 7.31                 | 7.0        |
| 14 P              | 6.07   | 6.64   | 6.17   | 6.29                   | 6.30   | 6.17   | 6.23                 | 6.0        |
| 15 P              | 5.42   | 5.99   | 5.77   | 5.73                   | 5.81   | 5.70   | 5.75                 | 5.0        |
| 16 Ck             | 6.78   | 7.01   | 6.97   | 6.92                   | 6.87   | 6.83   | 6.85                 |            |
| 17 P              | 4.68   | 4.98   | 5.94   | 5.03                   | 5.20   | 5.28   | 5.24                 | 4.0        |
| 18 Ck             | 6.57   | 6.80   | 6.90   | 6.76                   | 6.83   | 6.76   | 6.79                 |            |
| 19 N              | 6.04   | 6.60   | 6.26   | 6.30                   | 6.58   | 6.40   | 6.49                 | 6.0        |
| 20 O. P. N. Na    | 5.66   | 5.92   | 6.03   | 5.87                   | 6.45   | 7.23   | 6.84                 |            |

in Tables 3 and 4 indicate the treatment given the soil of each plot. They will be used in other tables with the same meanings, which are as follows:

O. Ck.—old soil check (used previous year in the greenhouse).

N. Ck.—new soil check (fresh soil plus  $\frac{1}{3}$  compost at the start of crop 3).

O. P. —old soil plus phosphoric acid.

N. Na.—new soil plus sodium carbonate.

Ck. —untreated soil (fresh soil plus  $\frac{1}{3}$  compost at the start of crop 1).

Ca. —ground limestone.

Ca<sub>1</sub>. —hydrated lime.

Na. —sodium carbonate.

S —sulfuric acid.

N —nitric acid.

P —phosphoric acid.

The pH desired is indicated in the tables and the amount of reagent added was regulated accordingly. If the reaction changed, additions were made to bring the pH to the desired

figure. The pH values for each crop are averages of 2 to 3 determinations, made by the quinhydrone electrode. The determinations were made before and after each crop, and sometimes when the crop was half grown.

TABLE 4. pH Values Obtained in the Tomato Plots.

| Plot               | Crop 1<br>(Fall) | Crop 2<br>(Spring) | Ave. Crops<br>1 & 2 | Crop 3<br>(Fall) | pH<br>Desired |
|--------------------|------------------|--------------------|---------------------|------------------|---------------|
| 1 O. & N. Ck       | 5.95             | 6.31               | 6.13                | 6.96             |               |
| 2 Ck               | 6.18             | 6.75               | 6.46                | 7.14             |               |
| 3 Ca <sub>1</sub>  | 7.90             | 8.52               | 8.21                | 8.57             | 9             |
| 4 P                | 6.37             | 6.64               | 6.50                | 6.31             | 6             |
| 5 P                | 5.08             | 5.73               | 5.40                | 5.15             | 5             |
| 6 P                | 5.16             | 5.27               | 5.21                | 4.85             | 4             |
| 7 Ca               | 6.63             | 7.32               | 6.98                | 7.83             | 8             |
| 8 Ca               | 6.83             | 7.27               | 7.05                | 7.29             | 7             |
| 9 Na               | 8.54             | 8.49               | 8.52                | 8.45             | 9             |
| 10 Na              | 8.04             | 7.87               | 7.96                | 7.72             | 8             |
| 11 Na              | 7.63             | 7.46               | 7.54                | 7.32             | 7             |
| 12 S               | 6.34             | 6.08               | 6.21                | 6.22             | 6             |
| 13 S               | 5.31             | 5.30               | 5.30                | 5.15             | 5             |
| 14 S               | 4.90             | 5.00               | 4.95                | 4.33             | 4             |
| 15 N               | 6.16             | 6.50               | 6.33                | 6.55             | 6             |
| 16 Ck              | 6.66             | 7.16               | 6.91                | 7.05             |               |
| 17 N               | 5.88             | 6.07               | 5.98                | 5.73             | 5             |
| 18 Ca <sub>1</sub> | 7.84             | 8.60               | 8.22                | 8.47             | 9             |
| 19 P               | 6.29             | 5.90               | 6.09                | 5.35             | 4             |
| 20 Ca              | 7.00             | 7.34               | 7.17                | 8.10             | 8             |
| 21 P               | 5.53             | 5.50               | 5.51                | 5.78             | 5             |
| 22 P               | 6.27             | 6.33               | 6.30                | 6.46             | 6             |
| 23 Ck              | 6.90             | 7.08               | 6.99                | 7.02             |               |
| 24 N               | 6.04             | 6.53               | 6.28                | 6.93             | 6             |
| 25 Na              | 8.03             | 8.32               | 8.17                | 8.40             | 9             |
| 26 Na              | 8.02             | 7.72               | 7.87                | 7.52             | 8             |
| 27 Na              | 7.46             | 7.31               | 7.38                | 7.31             | 7             |
| 28 S               | 5.04             | 4.55               | 4.79                | 4.93             | 4             |
| 29 S               | 5.34             | 4.96               | 5.15                | 5.33             | 5             |
| 30 S               | 5.98             | 6.00               | 5.99                | 6.14             | 6             |
| 31 N               | 5.80             | 5.82               | 5.81                | 5.97             | 5             |
| 32 Ck              | 6.55             | 6.98               | 6.76                | 7.06             |               |
| 33 O. P.<br>N. Na  | 5.57             | 6.36               | 5.96                | 7.86             |               |

#### YIELDS OF TOMATOES AND LETTUCE

The total yield of tomato fruit is given in Table 5 and that of lettuce foliage, in Table 6. Tomatoes which developed blossom end rot to such an extent that they were unmarketable were not included. Fruits possessing slight injury but still marketable, were included. The entire part of the plant above ground was included in the lettuce yields. Records were kept of dates of harvesting and the number of fruits picked, but the value of these details did not warrant their inclusion.



The weights are in terms of the avoirdupois ounce which equals 28.35 grams.

TABLE 5. Yield of Tomatoes. Stated as Ounces Per Plant.

| Plot               | Crop 1* | Crop 2 | Crop 3 |
|--------------------|---------|--------|--------|
| 1 O. & N. Ck.      | 3.66    | 88.0   | 34.0   |
| 2 Ck               | 17.0    | 89.5   | 38.3   |
| 3 Ca <sub>1</sub>  | 15.2    | 67.0   | 29.0   |
| 4 P                | 23.7    | 89.0   | 25.5   |
| 5 P                | 14.4    | 138.0  | 33.3   |
| 6 P                | 15.0    | 112.5  | 17.7   |
| 7 Ca               | 11.7    | 130.5  | 50.8   |
| 8 Ca               | 10.7    | 134.5  | 52.3   |
| 9 Na               | 4.8     | 176.0  | 24.7   |
| 10 Na              | 15.5    | 163.0  | 51.8   |
| 11 Na              | 16.7    | 136.5  | 50.2   |
| 12 S               | 9.2     | 156.0  | 36.3   |
| 13 S               | 15.3    | 78.5   | 37.0   |
| 14 S               | 9.3     | 62.5   | 36.8   |
| 15 N               | 14.7    | 178.0  | 37.0   |
| 16 Ck              | 19.8    | 139.5  | 49.2   |
| 17 N               | 15.2    | 39.5   | 37.7   |
| 18 Ca <sub>1</sub> | 14.3    | 153.5  | 65.7   |
| 19 P               | 10.0    | 90.5   | 33.8   |
| 20 Ca              | 18.2    | 112.0  | 50.8   |
| 21 P               | 16.2    | 150.0  | 52.5   |
| 22 P               | 17.2    | 94.0   | 44.8   |
| 23 Ck              | 22.5    | —      | 48.3   |
| 24 N               | 9.2     | 92.0   | 54.7   |
| 25 Na              | 9.5     | 193.0  | 39.0   |
| 26 Na              | 20.8    | 140.5  | 57.5   |
| 27 Na              | 15.3    | 123.5  | 62.8   |
| 28 S               | 12.0    | 74.0   | 48.3   |
| 29 S               | 20.5    | 116.0  | 34.5   |
| 30 S               | 19.3    | 120.0  | 46.3   |
| 31 N               | 7.5     | 47.0   | 25.3   |
| 32 Ck              | 12.5    | 67.5   | 45.0   |
| 33 O. P.<br>N Na   | 1.3     | 40.5   | 33.2   |

\*Because this crop was injured badly by nematodes, the yields should not be considered significant.

TABLE 6. Yield of Lettuce. Stated as Ounces Per Plant.

| Plot              | Crop<br>1 | Crop<br>2 | Crop<br>3 | Ave.<br>1928-<br>1929 | Crop<br>4 | Crop<br>5 | Ave.<br>1929-<br>1930 |
|-------------------|-----------|-----------|-----------|-----------------------|-----------|-----------|-----------------------|
| 1 O. & N. Ck      | 0.07      | 0.01      | 0.14      | 0.07                  | 3.01      | 2.67      | 2.84                  |
| 2 Ck              | 3.43      | 3.08      | 3.29      | 3.23                  | 2.42      | 2.60      | 2.51                  |
| 3 Ca <sub>1</sub> | 4.21      | 4.35      | 4.86      | 4.47                  | 3.23      | 2.95      | 3.09                  |
| 4 Ca <sub>1</sub> | 3.64      | 4.22      | 6.71      | 4.86                  | 3.81      | 3.46      | 3.65                  |
| 5 Ca              | 3.93      | 3.38      | 7.14      | 4.82                  | 3.62      | 3.73      | 3.68                  |
| 6 S               | 3.43      | 4.00      | 7.29      | 4.91                  | 4.46      | 4.31      | 4.38                  |
| 7 S               | 4.00      | 4.07      | 6.86      | 4.98                  | 4.04      | 4.13      | 4.09                  |
| 8 S               | 2.85      | 3.50      | 5.64      | 4.00                  | 3.57      | 3.63      | 3.60                  |
| 9 N               | 2.50      | 2.79      | 1.57      | 2.29                  | 0.93      | 3.66      | 2.30                  |
| 10 Ck             | 4.14      | 3.22      | 6.21      | 4.52                  | 3.31      | 4.99      | 4.15                  |
| 11 Na             | 2.29      | 5.22      | 5.14      | 4.22                  | 3.70      | 3.98      | 3.84                  |
| 12 Na             | 3.93      | 5.00      | 8.50      | 5.81                  | 4.56      | 4.43      | 4.50                  |
| 13 Na             | 4.00      | 4.50      | 8.14      | 5.55                  | 4.03      | 3.60      | 3.82                  |
| 14 P              | 3.07      | 3.29      | 7.14      | 4.50                  | 4.23      | 3.33      | 3.78                  |
| 15 P              | 3.79      | 3.57      | 6.36      | 4.57                  | 4.51      | 4.01      | 4.26                  |
| 16 Ck             | 3.79      | 4.50      | 6.21      | 4.83                  | 4.08      | 3.42      | 3.75                  |
| 17 P              | 2.93      | 3.79      | 6.21      | 4.31                  | 3.61      | 3.42      | 3.52                  |
| 18 Ck             | 3.71      | 3.29      | 5.21      | 4.07                  | 3.48      | 3.00      | 3.24                  |
| 19 N              | 3.71      | 2.93      | 3.71      | 3.45                  | 2.17      | 3.10      | 2.64                  |
| 20 O. P.<br>N. Na | 0.36      | 0.36      | 1.21      | 0.64                  | 3.40      | 3.78      | 3.59                  |

## NITRATE NITROGEN IN THE SOIL

Tables 7 and 8 give the content of nitrate nitrogen found in the soil at different times. Three samplings were made during the growth of the first crop of tomatoes and two for all other crops, except the fifth crop of lettuce, for which one sampling served. The findings were averaged with those from the second sampling for Crop 4, to get the average for Crop 5.

TABLE 7. Nitrate Nitrogen in Soil During the Growth of Three Crops of Tomatoes. Stated as Parts Per Million of Dry Soil.

| Plot               | 11/12/28 | 12/14/28 | 1/10/29 | Average for Crop 1 | 2/4/29 | 3/14/29 | Average for Crop 2 | 9/25/29 | 1/6/30 | Average for Crop 3 | Average for Crops 1 and 2 1928-1929 |
|--------------------|----------|----------|---------|--------------------|--------|---------|--------------------|---------|--------|--------------------|-------------------------------------|
| 1 O. & N.          | 813      | 575      | 1125    | 838                | 630    | 288     | 459                | 115     | 25     | 70                 | 648                                 |
| 2 Ck               | 88       | 24       | 40      | 51                 | 77     | 29      | 53                 | 21      | 3.5    | 13                 | 52                                  |
| 3 Ca <sub>1</sub>  | 95       | 43       | 65      | 68                 | 85     | 29      | 57                 | 40      | 25.0   | 33                 | 62                                  |
| 4 P                | 93       | 14       | 17      | 41                 | 39     | 14      | 27                 | 41      | 5.0    | 26                 | 31                                  |
| 5 P                | 80       | 12       | 3       | 32                 | 43     | 14      | 29                 | 17      | 6.2    | 12                 | 24                                  |
| 6 P                | 63       | 20       | 4       | 29                 | 28     | 13      | 21                 | 13      | 1.3    | 7                  | 19                                  |
| 7 Ca               | 54       | 12       | 5       | 24                 | 30     | 11      | 21                 | 24      | 4.0    | 14                 | 20                                  |
| 8 Ca               | 95       | 11       | 8       | 38                 | 40     | 10      | 25                 | 21      | 7.5    | 14                 | 28                                  |
| 9 Na               | 110      | 43       | 40      | 64                 | 93     | 16      | 55                 | 16      | 10.0   | 13                 | 44                                  |
| 10 Na              | 80       | 29       | 13      | 41                 | 55     | 14      | 35                 | 21      | 5.0    | 13                 | 38                                  |
| 11 Na              | 95       | 17       | 6       | 39                 | 70     | 15      | 43                 | 21      | 3.5    | 12                 | 31                                  |
| 12 S               | 68       | 21       | 8       | 32                 | 49     | 9       | 29                 | 6       | 4.5    | 5                  | 22                                  |
| 13 S               | 68       | 22       | 7       | 32                 | 29     | 8       | 19                 | 8       | 2.1    | 5                  | 19                                  |
| 14 S               | 80       | 12       | 3       | 32                 | 17     | 8       | 13                 | 11      | 1.3    | 6                  | 17                                  |
| 15 N               | 150      | 123      | 67      | 113                | 54     | 30      | 42                 | 113     | 4.5    | 59                 | 71                                  |
| 16 Ck              | 111      | 25       | 3       | 46                 | 25     | 7       | 16                 | 19      | 8.0    | 13                 | 25                                  |
| 17 N               | 440      | 340      | 40      | 273                | 195    | 95      | 145                | 625     | 150.0  | 388                | 268                                 |
| 18 Ca <sub>1</sub> | 78       | 38       | 13      | 43                 | 38     | 16      | 27                 | 140     | 75.0   | 107                | 59                                  |
| 19 P               | 80       | 20       | 9       | 36                 | 29     | 8       | 19                 | 67      | 12.5   | 40                 | 32                                  |
| 20 Ca              | 63       | 13       | 9       | 28                 | 38     | 7       | 23                 | 100     | 40.0   | 70                 | 40                                  |
| 21 P               | 45       | 14       | 5       | 31                 | 31     | 11      | 21                 | 67      | 6.0    | 37                 | 30                                  |
| 22 P               | 64       | 16       | 4       | 28                 | 29     | 7       | 18                 | 83      | 6.0    | 45                 | 30                                  |
| 23 Ck              | 65       | 11       | 3       | 26                 | 30     | 10      | 20                 | 130     | 10.0   | 70                 | 23                                  |
| 24 N               | 203      | 125      | 50      | 126                | 34     | 37      | 36                 | 188     | 26.0   | 107                | 90                                  |
| 25 Na              | 60       | 49       | 29      | 46                 | 37     | 12      | 25                 | 125     | 20.0   | 73                 | 48                                  |
| 26 Na              | 70       | 32       | 23      | 42                 | 53     | 10      | 32                 | 138     | 13.2   | 76                 | 50                                  |
| 27 Na              | 58       | 18       | 8       | 31                 | 32     | 13      | 23                 | 138     | 6.0    | 72                 | 42                                  |
| 28 S               | 63       | 11       | 3       | 26                 | 19     | 10      | 14                 | 35      | 4.5    | 20                 | 20                                  |
| 29 S               | 10       | 25       | 4       | 33                 | 18     | 9       | 14                 | 48      | 12.0   | 30                 | 29                                  |
| 30 S               | 50       | 28       | 4       | 27                 | 22     | 13      | 23                 | 75      | 27.5   | 51                 | 33                                  |
| 31 N               | 350      | 160      | 33      | 181                | 38     | 95      | 67                 | 700     | 250.0  | 475                | 241                                 |
| 32 Ck              | 100      | 25       | 5       | 43                 | 25     | 14      | 20                 | —       | 75.0   | 75                 | 46                                  |
| 33 O. & N.         | 887      | 750      | 585     | 741                | 540    | 270     | 405                | 324     | 87.5   | 206                | 573                                 |

TABLE 8. Nitrate Nitrogen in Soil During the Growth of Five Crops of Lettuce. Stated as Parts Per Million of Dry Soil.

| Plot              | 11/12/28 | 12/16/28 | Ave. for<br>(Crop 1 | 1/10/29 | 2/5/29 | Ave. for<br>(Crop 2 | 3/14/29 | 4/1/29 | Ave. for<br>(Crop 3 | 10/21/29 | 12/6/29 | Ave. for<br>(Crop 4 | 3/6/30 | Ave. for<br>(Crop 5 | Ave. Crops<br>1928-1929 | Ave. Crops<br>1929-1930 |
|-------------------|----------|----------|---------------------|---------|--------|---------------------|---------|--------|---------------------|----------|---------|---------------------|--------|---------------------|-------------------------|-------------------------|
| 1 O. & N.         | 650      | 500      | 575                 | 975     | 975    | 975                 | 952     | 800    | 876                 | 125      | 100     | 113                 | 35     | 68                  | 608                     | 90                      |
| 2 Ck              | 79       | 85       | 82                  | 43      | 40     | 42                  | 72      | 52     | 62                  | 100      | 75      | 88                  | 37     | 56                  | 62                      | 72                      |
| 3 Ca <sub>1</sub> | 90       | 75       | 83                  | 59      | 60     | 60                  | 61      | 50     | 56                  | 100      | 50      | 75                  | 20     | 35                  | 66                      | 55                      |
| 4 Ca <sub>2</sub> | 83       | 85       | 84                  | 48      | 33     | 41                  | 40      | 28     | 34                  | 150      | 85      | 118                 | 25     | 55                  | 52                      | 86                      |
| 5 Ca              | 90       | 70       | 80                  | 45      | 44     | 45                  | 64      | 40     | 52                  | 110      | 85      | 98                  | 20     | 53                  | 65                      | 75                      |
| 6 S               | 52       | 65       | 59                  | 34      | 33     | 34                  | 57      | 11     | 34                  | 65       | 75      | 70                  | 20     | 48                  | 49                      | 42                      |
| 7 S               | 75       | 60       | 68                  | 35      | 48     | 42                  | 46      | 9      | 28                  | 130      | 85      | 107                 | 23     | 54                  | 60                      | 80                      |
| 8 S               | 45       | 85       | 65                  | 43      | 50     | 46                  | 50      | 25     | 37                  | 85       | 75      | 80                  | 33     | 54                  | 49                      | 67                      |
| 9 N               | 640      | 450      | 545                 | 325     | 200    | 263                 | 950     | 600    | 775                 | 350      | 500     | 425                 | 113    | 397                 | 528                     | 366                     |
| 10 Ck             | 80       | 60       | 70                  | 40      | 42     | 41                  | 72      | 43     | 58                  | 120      | 100     | 110                 | 35     | 68                  | 69                      | 89                      |
| 11 Na             | 118      | 115      | 117                 | 70      | 102    | 86                  | 75      | 70     | 73                  | 125      | 130     | 128                 | 53     | 92                  | 99                      | 110                     |
| 12 Na             | 50       | 100      | 75                  | 49      | 90     | 70                  | 48      | 35     | 42                  | 150      | 120     | 135                 | 45     | 83                  | 81                      | 109                     |
| 13 Na             | 73       | 75       | 74                  | 40      | 88     | 64                  | 56      | 18     | 37                  | 130      | 125     | 128                 | 35     | 80                  | 77                      | 104                     |
| 14 P              | 63       | 90       | 76                  | 38      | 50     | 44                  | 40      | 20     | 30                  | 60       | 95      | 77                  | 20     | 58                  | 57                      | 67                      |
| 15 P              | 73       | 70       | 72                  | 44      | 40     | 42                  | 47      | 35     | 41                  | 100      | 115     | 107                 | 25     | 70                  | 66                      | 88                      |
| 16 Ck             | 98       | 95       | 96                  | 49      | 54     | 52                  | 47      | 15     | 31                  | 125      | 95      | 110                 | 20     | 58                  | 69                      | 84                      |
| 17 P              | 45       | 80       | 62                  | 45      | 52     | 48                  | 47      | 28     | 38                  | 60       | 75      | 67                  | 23     | 49                  | 53                      | 58                      |
| 18 Ck             | 53       | 75       | 64                  | 40      | 54     | 47                  | 73      | 45     | 59                  | 135      | 110     | 122                 | 23     | 67                  | 72                      | 94                      |
| 19 N              | 173      | 225      | 199                 | 140     | 105    | 123                 | 338     | 350    | 344                 | 140      | 400     | 170                 | 63     | 232                 | 213                     | 201                     |
| 20 O. P. N        | 480      | 1000     | 740                 | 301     | 752    | 527                 | 290     | 250    | 270                 | 150      | 110     | 130                 | 45     | 78                  | 512                     | 104                     |



## NITRATE NITROGEN IN TOMATO AND LETTUCE TISSUES

Table 9 gives the results of the determinations of the nitrate nitrogen in tomato tissues, and Table 10, those in lettuce tissues. Other determinations made without regard to age of tissue or percentage of veins were so inconsistent that they were not included in the tables.

TABLE 9. Nitrate Nitrogen in Tomato Tissues. Stated as Parts Per Million of Green Tissue.

| Plot               | Sucker Leaves     | Growing Tips       | Stems or Suckers  | Petioles Next to Stem | Upper Mature Leaves |
|--------------------|-------------------|--------------------|-------------------|-----------------------|---------------------|
|                    | Crop 1<br>12/5/28 | Crop 1<br>12/15/28 | Crop 2<br>3/28/29 | Crop 3<br>10/18/29    | Crop 3<br>11/24/29  |
| 1 O. & N. Ck       | —                 | 400                | —                 | 2750                  | 325                 |
| 2 Ck               | 136               | 156                | —                 | 2500                  | 250                 |
| 3 Ca <sub>1</sub>  | 174               | 125                | —                 | 2750                  | 450                 |
| 4 P                | 124               | —                  | —                 | 2750                  | 325                 |
| 5 P                | 75                | 113                | —                 | 2000                  | 225                 |
| 6 P                | 91                | 106                | —                 | 1750                  | 100                 |
| 7 Ca               | 104               | 94                 | 950               | 3000                  | 175                 |
| 8 Ca               | 80                | 75                 | 1000              | 2500                  | 325                 |
| 9 Na               | 83                | 125                | 1200              | 3000                  | 500                 |
| 10 Na              | —                 | 100                | 1100              | 3000                  | 300                 |
| 11 Na              | 83                | 80                 | 1100              | 2750                  | 225                 |
| 12 S               | 250               | 380                | 1400              | 2250                  | 67                  |
| 13 S               | 231               | 200                | —                 | 1500                  | 50                  |
| 14 S               | 338               | 137                | 1430              | 1250                  | 42                  |
| 15 N               | 275               | 133                | —                 | 3000                  | 375                 |
| 16 Ck              | 207               | 125                | 950               | 2250                  | 250                 |
| 17 N               | 263               | 240                | —                 | 3250                  | 425                 |
| 18 Ca <sub>1</sub> | 119               | 80                 | 1130              | 2500                  | 275                 |
| 19 P               | —                 | 75                 | —                 | 2000                  | 275                 |
| 20 Ca              | 113               | 150                | 1200              | 2750                  | 225                 |
| 21 P               | 117               | 150                | 1000              | 2000                  | 125                 |
| 22 P               | 88                | 85                 | 1025              | 2250                  | 150                 |
| 23 Ck              | 188               | 150                | 1150              | 2500                  | 250                 |
| 24 N               | 294               | 250                | 1150              | 2500                  | 200                 |
| 25 Na              | 157               | 140                | 1200              | 2250                  | 500                 |
| 26 Na              | 109               | 106                | 1150              | 2750                  | 375                 |
| 27 Na              | 117               | 112                | 1325              | 2250                  | 275                 |
| 28 S               | 166               | 75                 | 1380              | 1750                  | 200                 |
| 29 S               | 125               | 212                | 1400              | 2000                  | 150                 |
| 30 S               | 176               | 239                | 1450              | 1750                  | 225                 |
| 31 N               | 138               | 133                | —                 | 3000                  | 550                 |
| 32 Ck              | 92                | 125                | 120               | 2500                  | 225                 |
| 33 O. P. N. Na.    | 159               | 376                | —                 | 2750                  | 275                 |

TABLE 10. Nitrate Nitrogen in Lettuce Tissues. Stated as Parts Per Million of Green Tissue.

| Plot              | Young<br>Leaves    | Mature<br>Leaves,<br>Outer Fringe | Mature<br>Leaves  | Large<br>Midrib   |
|-------------------|--------------------|-----------------------------------|-------------------|-------------------|
|                   | Crop 2<br>11/18/29 | Crop 4<br>11/8/29                 | Crop 4<br>11/8/29 | Crop 4<br>11/8/29 |
| 1 O. & N. Ck.     | 243                | —                                 | —                 | 1700              |
| 2 Ck              | 113                | 463                               | —                 | 1000.             |
| 3 Ca <sub>1</sub> | 83                 | 413                               | 850               | 1400              |
| 4 Ca <sub>1</sub> | 78                 | 363                               | 700               | —                 |
| 5 Ca              | 95                 | 375                               | 850               | 1300              |
| 6 S               | 110                | 413                               | 1000              | 1400              |
| 7 S               | 113                | 463                               | 700               | 1300              |
| 8 S               | 133                | 500                               | 700               | 1400              |
| 9 N               | 128                | 1375                              | 1700              | 4000              |
| 10 Ck             | 116                | 463                               | 800               | 1400              |
| 11 Na             | 113                | 438                               | 900               | 1700              |
| 12 Na             | 87                 | 750                               | 875               | 1800              |
| 13 Na             | 106                | 513                               | 950               | 1700              |
| 14 P              | 122                | 375                               | 750               | 1300              |
| 15 P              | 116                | 363                               | 875               | 1300              |
| 16 Ck             | 122                | —                                 | 900               | 1200              |
| 17 P              | 106                | —                                 | 1000              | 1000              |
| 18 Ck             | 125                | —                                 | 900               | 1300              |
| 19 N              | 129                | —                                 | 1500              | 1800              |
| 20 O. P. N. Na.   | 188                | —                                 | 950               | 1500              |

**TOTAL NITROGEN IN TOMATO AND LETTUCE TISSUES**

The results of the determinations of total nitrogen in tomato tissues are given in Table 11, and in lettuce tissues in Table 12.

**TABLE 11. Total Nitrogen in Tomato Tissues. Stated as percent of the Green Tissue.**

| Plot               | Fruit  | Leaves |
|--------------------|--------|--------|
|                    | Crop 1 | Crop 3 |
| 1 O. & N. Ck       | 1.81   |        |
| 2 Ck               | 0.25   | 0.45   |
| 3 Ca <sub>1</sub>  |        | 0.45   |
| 4 P <sub>1</sub>   |        |        |
| 5 P                | 0.14   |        |
| 6 P                | 0.17   | 0.30   |
| 7 Ca               | 0.20   |        |
| 8 Ca               | 0.18   |        |
| 9 Na               | 0.16   | 0.50   |
| 10 Na              | 0.16   |        |
| 11 Na              | 0.17   |        |
| 12 S               | 0.19   |        |
| 13 S               | 0.20   |        |
| 14 S               | 0.25   | 0.55   |
| 15 N               | 0.25   |        |
| 16 Ck              | 0.27   | 0.40   |
| 17 N               | 0.29   | 0.50   |
| 18 Ca <sub>1</sub> | 0.19   | 0.45   |
| 19 P               |        | 0.35   |
| 20 Ca              | 0.20   |        |
| 21 P               | 0.19   |        |
| 22 P               | 0.18   |        |
| 23 Ck              | 0.22   |        |
| 24 N               | 0.25   |        |
| 25 Na              | 0.22   |        |
| 26 Na              | 0.21   | 0.50   |
| 27 Na              |        |        |
| 28 S               | 0.25   | 0.55   |
| 29 S               | 0.22   |        |
| 30 S               | 0.27   |        |
| 31 N               | 0.27   | 0.40   |
| 32 Ck              | 0.23   |        |
| 33 O. P.<br>N. Na  | 0.32   |        |

**TABLE 12. Total Nitrogen in Lettuce Tissues. Stated as Percent of Green Leaves and Dry Roots.**

| Plot              | Roots            | Roots  | Entire Leaves | Outer Fringe of Leaves | Midrib Crop 4 |
|-------------------|------------------|--------|---------------|------------------------|---------------|
|                   | Crop 2<br>3/5/29 | Crop 3 | Crop 3        | 11/19/30               | 11/19/30      |
| 1 O. & N. Ck      |                  |        |               | 0.41                   | 0.17          |
| 2 Ck              | 1.50             | 2.31   | 0.45          | 0.32                   | 0.18          |
| 3 Ca <sub>i</sub> | 1.70             | 2.50   | 0.54          | 0.28                   | 0.20          |
| 4 Ca <sub>i</sub> | 1.67             | 2.22   | 0.50          | 0.32                   | 0.17          |
| 5 Ca              | 2.62             | 2.54   | 0.51          | 0.26                   |               |
| 6 S               |                  | 2.17   | 0.40          | 0.21                   |               |
| 7 S               | 1.65             | 2.02   | 0.43          | 0.22                   | 0.17          |
| 8 S               | 1.78             | 1.92   | 0.42          | 0.24                   | 0.11          |
| 9 N               | 2.50             | 2.14   | 0.60          | 0.24                   | 0.29          |
| 10 Ck             | 2.19             | 2.38   | 0.46          | 0.31                   | 0.17          |
| 11 Na             | 2.25             | 2.65   | 0.51          | 0.33                   | 0.19          |
| 12 Na             | 2.00             | 2.48   | 0.48          | 0.30                   | 0.19          |
| 13 Na             | 2.00             | 2.44   | 0.48          | 0.25                   | 0.16          |
| 14 P              | 2.38             | 2.31   | 0.40          | 0.24                   | 0.11          |
| 15 P              | 2.00             | 2.50   | 0.40          | 0.27                   | 0.14          |
| 16 Ck             | 1.82             | 2.58   | 0.45          | 0.30                   | 0.16          |
| 17 P              | 2.50             | 2.02   | 0.54          | 0.19                   | 0.12          |
| 18 Ck             | 2.00             | 2.35   | 0.45          | 0.27                   | 0.18          |
| 19 N              | 2.50             | 2.45   | 0.51          | 0.22                   | 0.16          |
| 20 O. P.<br>N. Na | 3.00             | 2.54   |               | 0.23                   | 0.19          |

# **TOTAL NITROGEN IN THE SOIL**

Tables 13 and 14 show the results of the determinations of total nitrogen in the soil of the lettuce plots and of the tomato plots. Total nitrogen determinations were made only in the second season of the treatments.



TABLE 13. Total Nitrogen in the Soil During the Growth of Lettuce. Stated as Percent of the Air-Dried Soil.

| Plot              | 10/21/29 | 12/6/29 | 3/6/30 | Ave.<br>Crop 4 | Ave.<br>Crop 5 |
|-------------------|----------|---------|--------|----------------|----------------|
| 1 N               | 0.188    | 0.200   | 0.220  | 0.194          | 0.210          |
| Ck                |          |         |        |                |                |
| 2 Ck              | 0.138    | 0.180   | 0.200  | 0.159          | 0.190          |
| 3 Ca <sub>1</sub> | 0.138    | 0.200   | 0.180  | 0.169          | 0.190          |
| 4 Ca              | 0.175    | 0.220   | 0.200  | 0.198          | 0.210          |
| 5 Ca              | 0.163    | 0.200   | 0.180  | 0.182          | 0.190          |
| 6 S               | 0.138    | 0.220   | 0.220  | 0.179          | 0.220          |
| 7 S               | 0.150    | 0.180   | 0.200  | 0.165          | 0.190          |
| 8 S               | 0.113    | 0.160   | 0.220  | 0.136          | 0.190          |
| 9 N               | 0.200    | 0.240   | 0.240  | 0.220          | 0.240          |
| 10 Ck             | 0.150    | 0.180   | 0.220  | 0.165          | 0.200          |
| 11 Na             | 0.188    | 0.220   | 0.260  | 0.204          | 0.240          |
| 12 Na             | 0.175    | 0.240   | 0.220  | 0.208          | 0.230          |
| 13 Na             | 0.163    | 0.220   | 0.240  | 0.192          | 0.230          |
| 14 P              | 0.113    | 0.180   | 0.240  | 0.147          | 0.210          |
| 15 P              | 0.150    | 0.240   | 0.220  | 0.185          | 0.230          |
| 16 Ck             | 0.138    | 0.170   | 0.220  | 0.154          | 0.195          |
| 17 P              | 0.150    | 0.200   | 0.220  | 0.175          | 0.210          |
| 18 Ck             | 0.163    | 0.170   | 0.200  | 0.166          | 0.185          |
| 19 N              | 0.175    | 0.230   | 0.240  | 0.202          | 0.235          |
| 20 N              | 0.213    | 0.200   | 0.280  | 0.207          | 0.240          |

TABLE 14. Total Nitrogen in the Soil During the Growth of Tomatoes. Stated as Percent of the Air-Dried Soil.

| Plot               | 3/15/29 | 9/25/29 | 12/6/29 | 1/6/30 | Ave. for<br>Crop 3 |
|--------------------|---------|---------|---------|--------|--------------------|
| 1 Ck N             |         | 0.213   |         | 0.210  | 0.212              |
| 2 Ck               | 0.175   | 0.150   | 0.175   | 0.180  | 0.168              |
| 3 Ca <sub>1</sub>  | 0.200   | 0.150   | 0.175   | 0.195  | 0.173              |
| 4 P                |         | 0.163   | 0.213   | 0.180  | 0.185              |
| 5 P                |         | 0.138   | 0.188   | 0.180  | 0.169              |
| 6 P                | 0.188   | 0.125   | 0.200   | 0.170  | 0.165              |
| 7 Ca               |         | 0.138   | 0.175   | 0.160  | 0.158              |
| 8 Ca               | 0.175   | 0.150   | 0.200   | 0.190  | 0.180              |
| 9 Na               | 0.238   | 0.200   | 0.200   | 0.170  | 0.190              |
| 10 Na              |         | 0.175   | 0.213   | 0.180  | 0.189              |
| 11 Na              |         | 0.175   | 0.175   | 0.180  | 0.177              |
| 12 S               |         | 0.138   |         | 0.190  | 0.164              |
| 13 S               |         | 0.150   | 0.150   | 0.170  | 0.157              |
| 14 S               | 0.150   | 0.138   | 0.175   | 0.170  | 0.161              |
| 15 N               |         | 0.213   | 0.188   | 0.210  | 0.204              |
| 16 Ck              | 0.150   | 0.150   | 0.200   | 0.180  | 0.176              |
| 17 N               |         | 0.250   | 0.225   | 0.220  | 0.232              |
| 18 Ca <sub>1</sub> | 0.169   | 0.188   | 0.250   | 0.200  | 0.213              |
| 19 P               |         | 0.150   | 0.213   | 0.180  | 0.181              |
| 20 Ca              | 0.156   | 0.175   | 0.225   | 0.190  | 0.197              |
| 21 P               |         | 0.163   | 0.213   | 0.180  | 0.185              |
| 22 P               |         | 0.125   | 0.275   | 0.150  | 0.183              |
| 23 Ck              |         | 0.163   |         | 0.175  | 0.169              |
| 24 N               |         | 0.175   | 0.225   | 0.200  | 0.200              |
| 25 Na              | 0.188   | 0.213   | 0.275   | 0.170  | 0.219              |
| 26 Na              |         | 0.168   | 0.238   | 0.200  | 0.202              |
| 27 Na              |         | 0.200   | 0.188   | 0.175  | 0.188              |
| 28 S               | 0.119   | 0.150   | 0.188   | 0.150  | 0.163              |
| 29 S               |         | 0.175   | 0.200   | 0.170  | 0.182              |
| 30 S               |         | 0.150   | 0.175   | 0.170  | 0.165              |
| 31 N               |         | 0.225   | 0.213   | 0.200  | 0.213              |
| 32 Ck              |         | 0.163   | 0.200   | 0.180  | 0.181              |
| 33 N               |         | 0.250   | 0.275   | 0.225  | 0.250              |
| Na                 |         |         |         |        |                    |

**FILTERABLE PHOSPHORUS IN THE SOIL AND PHOSPHATE  
PHOSPHORUS IN THE PLANT**

These were determined as described under methods of analysis. The findings are presented in Tables 15 and 16.

**TABLE 15. Filterable Phosphorus in the Soil and Phosphate Phosphorus in the Plant During the Growth of Tomatoes.**

| Plot               | Filterable P. as ppm. of air-dry soil |         |        |                    | Phosphate P. as ppm. of Green Tissue |                    |
|--------------------|---------------------------------------|---------|--------|--------------------|--------------------------------------|--------------------|
|                    | 2/4/29<br>Crop 2                      | 9/25/29 | 1/6/30 | Ave. for<br>Crop 3 | Mature<br>Leaves<br>Crop 3           | Petioles<br>Crop 4 |
| 1 O. & N.<br>Ck    | 20.9                                  | 43.2    | 17.6   | 30.4               | 158                                  | 534                |
| 2 Ck               | 68.5                                  | 19.2    | 8.2    | 13.7               | 127                                  | 556                |
| 3 Ca <sub>1</sub>  | 35.9                                  | 11.2    | 5.2    | 8.2                | 77                                   | 533                |
| 4 P                | 62.0                                  | 67.2    | 57.6   | 62.4               | 365                                  | 1164               |
| 5 P                | 281.1                                 | 280.0   | 102.4  | 191.2              | 706                                  | 1600               |
| 6 P                | 285.2                                 | 280.0   | 200.0  | 240.0              | 484                                  | 1032               |
| 7 Ca               | 9.9                                   | 24.0    | 10.2   | 17.1               | 105                                  | 820                |
| 8 Ca               | 11.4                                  | 16.0    | 8.0    | 12.0               | 100                                  | 820                |
| 9 Na               | 163.0                                 | 98.3    | 57.6   | 78.0               | 157                                  | 766                |
| 10 Na              | 105.9                                 | 25.6    | 14.4   | 20.0               | 115                                  | 628                |
| 11 Na              | 79.9                                  | 27.2    | 9.3    | 18.2               | 115                                  | 600                |
| 12 S               | 37.5                                  | 28.3    | 9.1    | 18.7               | 290                                  | 1403               |
| 13 S               | 51.3                                  | 26.4    | 26.4   | 26.4               | 334                                  | 1600               |
| 14 S               | 92.9                                  | 32.0    | 13.4   | 23.7               | 519                                  | 992                |
| 15 N               | 71.4                                  | 23.2    | 11.4   | 17.3               | 198                                  | 1048               |
| 16 Ck              | 66.8                                  | 24.8    | 8.6    | 16.7               | 167                                  | 1016               |
| 17 N               | 56.0                                  | 44.8    | 12.5   | 28.6               |                                      | 1524               |
| 18 Ca <sub>1</sub> | 26.1                                  | 10.7    | 5.6    | 8.1                | 110                                  | 1212               |
| 19 P               | 127.2                                 | 256.0   | 192.0  | 224.0              | 299                                  | 2000               |
| 20 Ca              | 47.2                                  | 24.0    | 8.3    | 16.1               | 163                                  | 1176               |
| 21 P               | 358.6                                 | 184.0   | 94.4   | 139.2              | 391                                  | 1916               |
| 22 P               | 105.9                                 | 64.0    | 51.2   | 57.6               | 259                                  | 1728               |
| 23 Ck              | 60.3                                  | 20.0    | 11.2   | 15.6               | 169                                  | 1332               |
| 24 N               | 63.5                                  | 24.0    | 12.2   | 18.1               | 149                                  | 1524               |
| 25 Na              | 115.8                                 | 89.1    | 44.0   | 66.6               | 246                                  | 1454               |
| 26 Na              | 102.7                                 | 79.0    | 25.6   | 52.3               | 251                                  | 1524               |
| 27 Na              | 83.1                                  | 33.6    | 10.6   | 22.1               | 245                                  | 1332               |
| 28 S               | 86.4                                  | 33.6    | 21.6   | 27.6               | 430                                  | 1652               |
| 29 S               | 70.1                                  | 32.0    | 17.4   | 24.7               | 345                                  | 1280               |
| 30 S               | 50.6                                  | 21.7    | 8.3    | 15.0               | 281                                  | 1280               |
| 31 N               | 62.0                                  | 28.3    | 11.2   | 19.7               | 464                                  | 1280               |
| 32 Ck              | 62.0                                  | 20.0    | 6.9    | 13.4               | —                                    | 1392               |
| 33 O. P.<br>N. Na  | 48.9                                  | 73.5    | 41.0   | 57.2               | 255                                  | 1524               |

TABLE 16. Filterable Phosphorus in the Soil and Phosphate Phosphorus in the Plant During the Growth of Lettuce.

| Filterable P. as ppm. of air-dry soil |         |        |                | Phosphate P. as ppm. of Green Tissue |                              |
|---------------------------------------|---------|--------|----------------|--------------------------------------|------------------------------|
| Plot                                  | 12/6/29 | 3/6/30 | Average Crop 5 | Mature Leaves 2/6/30 Crop 5          | Mature Leaves 2/10/30 Crop 5 |
| 1 O. & N.<br>Ck                       | 11.2    | 11.2   | 11.2           |                                      | 368                          |
| 2 Ck                                  | 8.6     | 6.4    | 7.5            | 344                                  | 320                          |
| 3 Ca <sub>1</sub>                     | 6.7     | 4.8    | 5.7            | 288                                  | 288                          |
| 4 Ca                                  | 7.4     | 9.6    | 8.5            | 342                                  | 272                          |
| 5 Ca                                  | 5.8     | 6.4    | 6.2            |                                      | 288                          |
| 6 S                                   | 8.6     | 7.4    | 8.0            |                                      | 328                          |
| 7 S                                   | 22.4    | 19.2   | 20.8           |                                      | 360                          |
| 8 S                                   | 25.6    | 24.0   | 24.8           |                                      | 392                          |
| 9 N                                   | 10.2    | —      | 10.2           | 448                                  | 320                          |
| 10 Ck                                 | 8.6     | 12.2   | 10.4           |                                      | 232                          |
| 11 Na                                 | 27.6    | 45.6   | 36.6           |                                      | 352                          |
| 12 Na                                 | 11.6    | 17.6   | 13.6           | 408                                  | 224                          |
| 13 Na                                 | 8.8     | 12.8   | 10.8           |                                      | 240                          |
| 14 P                                  | 48.0    | 48.0   | 48.0           |                                      | 224                          |
| 15 P                                  | 115.2   | 230.4  | 172.8          |                                      | 376                          |
| 16 Ck                                 | 8.2     | 15.4   | 11.8           |                                      | 232                          |
| 17 P                                  | 264.0   | 240.0  | 252.0          | 688                                  | 512                          |
| 18 Ck                                 | 9.4     | 18.6   | 14.0           |                                      | 304                          |
| 19 N                                  | 6.4     | 9.6    | 8.0            |                                      | 250                          |
| 20 Ck                                 | 11.1    | 44.0   | 27.6           |                                      | 416                          |

**TOTAL PHOSPHORUS IN TOMATO AND LETTUCE TISSUES**

Table 17 shows the quantity of total phosphorus found in fresh tomato fruits and dried lettuce leaves and roots.

**TABLE 17. Total Phosphorus in Tomato and Lettuce Tissues. Stated as Percent of the Fresh Fruit and of the Dry Leaves and Roots.**

| Tomato             |                 | Lettuce           |                             |                  |                 |
|--------------------|-----------------|-------------------|-----------------------------|------------------|-----------------|
| Plot               | Fruit<br>Crop 1 | Plot              | Leaves<br>Crop 2<br>2/22/29 | Leaves<br>Crop 3 | Roots<br>Crop 3 |
| 1 O. & N.<br>Ck    |                 | 1 O. & N.<br>Ck   |                             |                  |                 |
| 2 Ck               | 0.027           | 2 Ck              | 0.98                        | 1.00             | 1.24            |
| 3 Ca <sub>1</sub>  |                 | 3 Ca              | 0.78                        | 0.70             | 1.20            |
| 4 P                |                 | 4 Ca              | 1.08                        | 0.91             | 1.26            |
| 5 P                | 0.024           | 5 Ca              | 0.98                        | 0.92             | 1.27            |
| 6 P                | 0.028           | 6 S               | 1.00                        | 0.96             | 1.34            |
| 7 Ca               | 0.022           | 7 S               | 1.18                        | 1.08             | 1.35            |
| 8 Ca               |                 | 8 S               | 1.14                        | 1.04             | 1.37            |
| 9 Na               | 0.026           | 9 N               | 0.98                        | 0.97             | 1.28            |
| 10 Na              | 0.028           | 10 Ck             | 1.02                        | 0.94             | 1.23            |
| 11 Na              |                 | 11 Na             | 1.06                        | 0.98             | 1.23            |
| 12 S               | 0.028           | 12 Na             | 0.96                        | 1.09             | 1.36            |
| 13 S               | 0.027           | 13 Na             | 0.96                        | 1.04             | 1.32            |
| 14 S               | 0.036           | 14 P              | 0.92                        | 0.99             | 1.38            |
| 15 N               | 0.030           | 15 P              | 0.99                        | 1.01             | 1.52            |
| 16 Ck              | 0.027           | 16 Ck             |                             | 0.97             | 1.35            |
| 17 N               | 0.031           | 17 P              |                             | 1.00             | 1.68            |
| 18 Ca <sub>1</sub> | 0.018           | 18 Ck             |                             | 0.93             | 1.31            |
| 19 P               |                 | 19 N              |                             | 0.91             | 1.31            |
| 20 Ca              |                 | 20 O. P.<br>N. Na |                             |                  | 1.33            |
| 21 P               |                 |                   |                             |                  |                 |
| 22 P               | 0.021           |                   |                             |                  |                 |
| 23 Ck              | 0.027           |                   |                             |                  |                 |
| 24 N               | 0.030           |                   |                             |                  |                 |
| 25 Na              | 0.025           |                   |                             |                  |                 |
| 26 Na              | 0.029           |                   |                             |                  |                 |
| 27 Na              |                 |                   |                             |                  |                 |
| 28 S               | 0.023           |                   |                             |                  |                 |
| 29 S               | 0.023           |                   |                             |                  |                 |
| 30 S               | 0.022           |                   |                             |                  |                 |
| 31 N               |                 |                   |                             |                  |                 |
| 32 Ck              |                 |                   |                             |                  |                 |
| 33 O. P.<br>N. Na  |                 |                   |                             |                  |                 |



# FILTERABLE MANGANESE IN THE SOIL AND TOTAL IN TOMATO AND LETTUCE TISSUES

The quantity of manganese, extracted from the soil of the tomato plots in exactly the same way as for filterable phosphorus, except that larger quantities of soil were used, is stated in Table 18. The table also records the quantity of manganese found in tomato tissue from plants on the several plots. Table 19 gives the corresponding findings for lettuce.

TABLE 18. Filterable Manganese in the Soil During the Growth of Tomatoes and Total Manganese in the Plant. Stated as Parts Per Million.

| Plot               | Soil    |        |             | Green Tissue |
|--------------------|---------|--------|-------------|--------------|
|                    | 9/25/29 | 1/6/30 | Average     | Petioles     |
|                    | Crop 3  | Crop 4 | Crops 3 & 4 | Crop 4       |
| 1 O. Ck            |         |        |             |              |
| N. Ck              | 0.14    | 0.49   | 0.31        | 58.5         |
| 2 Ck               | 1.33    | 0.74   | 1.03        | 75.0         |
| 3 Ca <sub>1</sub>  | 0.25    | 0.12   | 0.18        | 63.0         |
| 4 P                | 0.25    | 0.98   | 0.62        | 96.5         |
| 5 P                | 3.50    | 1.73   | 2.62        | 310.0        |
| 6 P                | 10.60   | 5.78   | 8.19        | 860.0        |
| 7 Ca               | none    | 0.06   | 0.03        | —            |
| 8 Ca               | 0.50    | 0.12   | 0.31        | 88.8         |
| 9 Na               | 9.80    | 4.22   | 7.01        | 62.7         |
| 10 Na              | 1.75    | 0.98   | 1.36        | 66.7         |
| 11 Na              | 2.00    | 0.74   | 1.37        | 71.0         |
| 12 S               | 13.00   | 0.98   | 6.99        | 96.5         |
| 13 S               | 62.00   | 55.55  | 58.78       | 777.7        |
| 14 S               | 270.00  | 77.78  | 173.89      | 1055.5       |
| 15 N               | 8.30    | 1.85   | 5.07        | 120.0        |
| 16 Ck              | 3.30    | 0.25   | 1.78        | 86.0         |
| 17 N               | 3.10    | 0.61   | 1.85        | 133.3        |
| 18 Ca <sub>1</sub> | 0.28    | 0.     | 0.14        | 78.0         |
| 19 P               | 4.25    | 2.34   | 3.29        | 277.7        |
| 20 Ca              | none    | 0.06   | 0.03        | 81.0         |
| 21 P               | 0.90    | 0.98   | 0.94        | 205.0        |
| 22 P               | 0.56    | 0.12   | 0.34        | 133.3        |
| 23 Ck              | 0.50    | 0.25   | 0.38        | 81.0         |
| 24 N               | —       | 0.74   | 0.74        | 83.4         |
| 25 Na              | 10.00   | 3.11   | 6.55        | 66.7         |
| 26 Na              | 5.46    | 1.60   | 3.53        | 83.4         |
| 27 Na              | —       | 0.49   | 0.49        | 83.4         |
| 28 S               | 125.00  | 27.78  | 76.29       | 805.0        |
| 29 S               | 16.00   | 4.89   | 10.44       | 585.0        |
| 30 S               | 1.00    | 0.61   | 0.80        | 81.0         |
| 31 N               | 3.10    | 0.61   | 1.85        | 74.2         |
| 32 Ck              | 0.50    | 0.25   | 0.38        | 74.2         |
| 33 N. Na           | 2.03    | 0.98   | 1.50        | 66.7         |

TABLE 19. Filterable Manganese in the Soil During the Growth of Lettuce and Total Manganese in the Plant. Stated as Parts Per Million.

| Plot              | Soil   |        | Green Tissue |                  |
|-------------------|--------|--------|--------------|------------------|
|                   | 2/1/29 | 3/6/30 | Leaves       | Leaves and Veins |
|                   | Crop 2 | Crop 3 | Crop 3       | Crop 4           |
| 1 O. & N. Ck      | —      | 1.48   | —            | 10.0             |
| 2 Ck              | 0.43   | 0.49   | 2.1          | 6.9              |
| 3 Ca <sub>1</sub> | 0.35   | —      | 0.5          | 4.7              |
| 4 Ca <sub>1</sub> | —      | —      | 1.0          | 5.3              |
| 5 Ca              | —      | —      | 1.8          | 4.1              |
| 6 S               | —      | —      | 3.1          | 6.3              |
| 7 S               | —      | 1.73   | 3.5          | 14.0             |
| 8 S               | 8.80   | 20.56  | 10.1         | 33.3             |
| 9 N               | 0.32   | 0.74   | 5.0          | 8.8              |
| 10 Ck             | 0.24   | 1.48   | 3.0          | 5.0              |
| 11 Na             | 0.67   | 1.97   | 4.0          | 5.0              |
| 12 Na             | —      | 2.22   | —            | 3.0              |
| 13 Na             | —      | 0.98   | —            | 3.5              |
| 14 P              | —      | 0.74   | —            | 6.7              |
| 15 P              | —      | 0.98   | —            | 10.0             |
| 16 Ck             | —      | 0.98   | 4.3          | 4.5              |
| 17 P              | 1.38   | 6.67   | 7.5          | 13.8             |
| 18 Ck             | —      | 0.98   | —            | 6.3              |
| 19 N              | —      | 0.74   | —            | 8.5              |
| 20 O. P. N. Na.   | —      | 0.98   | —            | 5.0              |

## DISCUSSION OF RESULTS

*Variation of pH in the Soil.* Considerable variation of the pH occurred, as indicated in Tables 3 and 4. Only in a few instances was the change more than a pH unit. As long as the variation remained within this limit it was considered satisfactory, since it was not practicable to maintain an exact pH. That is, if the desired pH were 5, a reaction of from pH 4.5 to 5.5 was considered satisfactory.

It was found most difficult to maintain the extremes of the range, pH 4 and 9. The acid side was the hardest to maintain, especially with phosphoric acid. Nitric acid was rather difficult to keep present in the soil as it evidently reacted with the soil organic matter and also leached out readily. Sulfuric acid kept a more constant pH than the other acids. Sodium carbonate seemed to cause more fluctuation than lime, which was to be expected because it is much more soluble.

*Causes of Variation of pH.* Probably the three main

causes for fluctuation of pH are the neutralizing action of plants, the loss of the reagent by leaching, and the buffer action of the soil. All these bring about a tendency toward neutrality. Tables 3 and 4 show this tendency. The only chance for too strong acidity or alkalinity was in the addition of too much of the reagents. Hoagland (44) showed that the plant is very effective in changing a nutrient solution from extremes of acidity or alkalinity to very near neutrality. It is reasonable to infer that growing crops to maturity in a small volume of soil would exert a continuous neutralizing effect.

The plots used in these experiments were on raised benches with hot water pipes immediately beneath them. This caused rather rapid drying out and frequent applications of water were necessary. At each application much dripping occurred which carried out rather large amounts of the soluble reagents. This probably accounts in a large part for the necessity of adding more reagents to maintain the desired pH.

The buffer action of the soil, of course, came into action immediately after the addition of the reagents. However, it probably caused a continued effect on the reaction since some of the chemical and physical phenomena involved undoubtedly took time for completion.

*Change in Reaction of the Checks.* Examination of Tables 3 and 4 shows that the reaction in the check soil tended to become more alkaline the longer the soil remained in the greenhouse. This agrees with the conclusions in a previous paper (27), in which the increase in pH was ascribed to the regular application of alkaline hydrant water and to the formation of carbonates and bicarbonates in a soil containing much organic matter and under ideal conditions for bacterial action.

Alkalinity undoubtedly becomes injurious when the supply of organic matter is inadequate.

*Nitrate Content of the Soil.* In the check plots this decreased with the advance of the season. The following figures taken from Tables 7 and 8 show the trend:

Nitrate Nitrogen in the Check Soil, Ppm.

| Crop     | Season | 1st Sampling | 2nd Sampling |
|----------|--------|--------------|--------------|
| Tomatoes |        |              |              |
| Crop 1   | 1st    | 91           | 21           |
| Crop 2   | 1st    | 39           | 15           |
| Crop 3   | 2nd    | 63           | 7            |
| Lettuce  |        |              |              |
| Crop 1   | 1st    | 78           | 79           |
| Crop 2   | 1st    | 43           | 48           |
| Crop 3   | 1st    | 66           | 39           |
| Crop 4   | 2nd    | 120          | 95           |
| Crop 5   | 2nd    | 95           | 29           |

The increase in nitrate content the second season was due, in part, at least, to the partial sterilization of the soil in the treatment for nematodes. Some of the checks received medium rotted manure, with a consequent increase in nitrate content. This is shown by the checks 2 and 16, under crop 3 (Table 7), which contained 13 ppm. each, whereas checks 23 and 32 (manure added) contained 70 and 75 ppm., respectively. In some plots, however, there was little difference after addition of manure, especially in the lettuce plots.

The nitrate content of the soil was much diminished after the tomato crops, but not so much after lettuce. This shows that tomatoes are much heavier feeders for nitrate than lettuce. This is shown, also, by the smaller nitrate content of the soil at all times, in the tomato plots, than in the lettuce plots. The lower feeding power of lettuce may account for the small difference between check soil treated with manure and that which was not, in the lettuce plots.

Graph 1 shows the relative amounts of nitrate maintained in the soil. It is apparent that alkaline soil maintained much higher concentrations of nitrate than any other treatment except that with nitric acid. In most instances sodium carbonate increased the nitrate content of the soil more than calcium hydroxide and always more than calcium carbonate. In fact, the nitrate content was smaller following treatment with calcium carbonate than in the checks, in some instances, altho as a rule it was about the same. The higher pH values produced by

calcium hydroxide and sodium carbonate seemed to be required to increase nitrification. Phosphoric acid was less toxic to the nitrifiers than sulfuric acid.

In the soil on which lettuce grew, applications of calcium carbonate and hydroxide decreased the nitrate content below that of the check, especially after a time. This may have been due to a lack of active phosphorus, since very little filterable phosphorus was obtained from the limed soil. Only once (in the third crop of tomatoes) was the nitrate nitrogen content of the soil to which sodium carbonate had been added, smaller than that of the checks. The lowering of the energy supply by the rapid action of some of the chemicals on the organic matter, undoubtedly had a great influence on nitrification. This may explain some of the fluctuations. Sodium carbonate, especially, acts upon organic matter, probably making it more available as a source of energy for the nitrifiers, with a consequent increase of nitrification. It seems that the use of organic matter and sodium carbonate might be an effective way of increasing the nitrate content of a poor soil.

*Nonsymbiotic Nitrogen Fixation in the Soil.* Graph 3 shows the relative content of total nitrogen maintained in the soil at varying reactions. (Tables 13 and 14.) The proportion of total nitrogen follows about the same trend as that of the nitrate nitrogen. Indeed, the increase with an alkaline reaction is even greater. The depression with an acid reaction, however, is not so great. Phosphoric acid evidently stimulated some fixation, since the total nitrogen in the phosphoric acid plots is larger than in the checks. Stimulation of azofication\* by sodium carbonate is very marked. Fixation at the rate of 500 to 1000 pounds of nitrogen to the acre, in one season, is shown in Tables 13 and 14. Calcium hydroxide and carbonate tended to depress azofication somewhat, with time. As with nitrification, this may be connected with a tying up of phosphorus in the soil and the destruction of energy material.

The results in Tables 13 and 14 also indicate very clearly that in order to have azofication, plenty of organic matter must

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\*This term is taken to mean any nonsymbiotic fixation of nitrogen.



be present. In the soil to which manure was added at the beginning of the second year, azofication was increased in nearly all plots, altho some of the sodium-carbonate-treated soil without manure still seemed to fix nitrogen freely.

The question may be asked, why the acid soil, in some instances, lost total nitrogen? The conditions in the greenhouse bench are conducive to leaching and this, together with rapid absorption by the tomatoes, and little azofication, probably caused depression of the total nitrogen content.

*Suggested Practical Application.* It seems that it might pay a truck gardner to obtain nitrogen by azofication, if the proper organisms are present. Soil in the field might be made alkaline with sodium carbonate and lime (a pH of 7.3-7.6 probably would be necessary) and organic matter might be added to promote azofication. The organic matter need not contain nitrogen, hence any plant residues would answer the purpose. Sodium carbonate attacks plant residues even if they are of a coarse nature. Four tons of ground limestone and  $\frac{1}{2}$  ton of sodium carbonate per acre would bring an average soil to at least an immediate pH of 7.5. This would cost about \$10.00 for the limestone and \$20.00 for the sodium carbonate. Since crop residues can be used the organic matter would cost nothing except the labor involved. In this way the truck grower could fix nitrogen while growing crops. Of course, the crop grown must be one that will stand the necessary degree of alkalinity, such as tomatoes and lettuce.

A fixation of 250 pounds per acre should be relatively easy. This is equivalent to an addition of about 1500 pounds of sodium nitrate, which would cost about \$50.00. Thus the first year the nitrogen fixed would more than pay for the alkaline agents used, and the fixation would not stop then. Furthermore, the nitrogen would be in a non-leachable form, and would be made available at about the right rate by the nitrifiers which are also favored by alkaline reaction. Sodium carbonate would also maintain a favorable phosphorus supply and the sodium might take the place of potassium to some extent if potassium were deficient. After the first application of lime and sodium car-

bonate the expense of maintaining pH 7.5 would be small and nitrogen might be fixed for years to come by turning under crop residues of a non-leguminous nature.

But sodium carbonate is considered toxic. This is true if it is present in too large amount. But several tons to the acre, on ordinary soil would be required to give toxic effects. It is true that sodium carbonate causes bad physical condition in some soils, but if lime and plenty of organic matter were used it is probable that this effect would not be serious. Some puddling occurred in the greenhouse, but is soon disappeared.

The suggestion of a practical application is tentative. The plan must be tested thoroly in the field before a recommendation can be made.

A system of soil improvement in which alkalinity is depended on for the maintenance of the nitrogen supply would be comparable to that in the alkali soils of the west where the total nitrogen of the soil is steadily built up despite an intensive non-legume cultivation. Carter and Greaves (17) have shown that total nitrogen is increasing in Utah soils without the use of legumes or fertilizers. The humid region farmer would not be in danger of having excessive accumulation of alkali and nitrate such as occurs in the arid west. He would, however, have the disadvantage of having added alkali leached out, where drainage is excessive, or carried away by the runoff. In fact, some of the workers on alkali soils in the western United States have concluded that sodium carbonate is not the toxic compound in alkali soils. Breazeale (6) finds from the behavior of plants and by chemical analyses that sodium carbonate does not exist in toxic concentrations in ordinary black alkali soils. He finds that both sodium hydroxide and sodium carbonate act as stimulants to plants in all concentrations that are usually found in the solution of black alkali soils.

Riviere and Pichard (68) found that with equimolecular quantities of the carbonates of calcium, magnesium, sodium and potassium, added to a soil of pH 7.2, containing 1.4 to 1.6 percent of calcium carbonate, the greatest increase in the yield of wheat was obtained with sodium carbonate. They attributed this to

increases in nitrification, and the supply of sodium. The findings reported herein suggest that increased azofication following the addition of sodium carbonate may have contributed to the result.

*Transformations of Phosphorus Compounds.* The phosphorus extracted by the procedure described for "filterable phosphorus" was taken as an approximation of amount available to the plant. This procedure is justifiable, because it seems reasonable to assume that an estimate including both soluble and fine colloidal phosphorus compounds present in the natural soil should be nearer to the actual amount available than the amount extracted by some foreign solvent which alters the very nature of the soil. The use of colloidion bags, the method of Parker and Tidmore (66), or a Pasteur-Chamberland filter, extracts only water-soluble phosphorus. This is, however, not the only phosphorus available to plants, as has been proved many times.

Graph No. 4 shows that a definite relation exists between the quantity of filterable phosphorus extracted from the soil and the quantity of this element taken up by the plant.

The amount of filterable phosphorus increased with the amount of sulfuric acid added. Nitric acid did not cause much increase. Phosphoric acid, of course, added much water-soluble phosphorus. A pH of 4.5-5.5 had to be attained before the amount of filterable phosphorus became materially increased. Small amounts of sulfuric acid increased the filterable phosphorus only slightly more than that in the checks. Evidently, if any phosphorus was dissolved, it was locked up again by iron, aluminum, and manganese. The phosphorus made filterable on the acid side was probably in a soluble, not a colloidal compound.

In practically every test limestone decreased the amount of filterable phosphorus. Phosphate made available by throwing out iron, aluminum, and manganese hydroxides, was undoubtedly immediately reverted to insoluble tricalcium phosphate. Lime added to acid soil to lessen acidity may liberate phosphorus from insoluble phosphates of iron, aluminum and manganese, but evidently when the reaction is taken into the

alkaline range phosphorus is again locked up. The large quantity of filterable phosphorus in the sodium carbonate plots evidently was due partly to the large amount of colloidal material coming thru the filter and also to the solubility of sodium phosphate.

The amount of phosphorus in the plants from these plots was increased almost proportionately to that in the soil. In crop 4 of tomatoes the proportion of phosphate phosphorus (Table 12) in the petioles of the plants on the manured plots was much larger than in those on the unmanured plots. The filterable phosphorus was not followed for crop 4, but the last determination for crop 3 indicates some increases in the manured plots, tho not so marked as noted later in the plants.

*Transformations of Manganese Compounds.* Graph 6 shows in a striking manner the rapidity with which the proportion of filterable manganese increases with acidity. Sulfuric acid is especially effective in bringing manganese into solution. This probably explains a great part of its deleterious effect on plant growth. No tests were made for aluminum or iron, but probably these also are brought into solution. However, it is likely that a smaller quantity of manganese is required to produce toxic effects than of aluminum and iron. Brenchly (8) has shown that 10 p.p.m. of manganese in a nutrient solution produces deleterious effects on barley. Carr and Brewer (15) found that 300 pounds of soluble manganese thiocyanate per acre in the soil was toxic. Tables 18 and 19 show that at pH 4.5-5.4 there was as much as 540 pounds of filterable manganese per acre and at 5.5-6.5 as much as 124 pounds per acre. At pH 5.0-5.4, with phosphoric acid, there was only 21.2 pounds per acre, while with nitric acid the amount present was only a trifle above that in the check soils. It seems then that manganese was actually toxic only in the soils treated with sulfuric acid. Since many Kentucky soils contain much manganese (the checks in the present experiment contained 4200 p.p.m. as an average of several determinations of good duplication), and since sulfuric acid is one of the acids likely to be found in soils, it is reasonable to believe that a common deleterious effect of



acid soil is due to the manganese brought into ionic activity by the acids present.

Burgess (14) showed that the toxic effect of acid soils on lettuce correlated with the aluminum made active. At pH 5.5 he obtained a very small yield as compared with that at pH 7.8, and at pH 5.5, 650 p.p.m. of active  $\text{Al}_2\text{O}_3$  were present, whereas at pH 7.8 only 135 p.p.m. were present. Apparently 344 p.p.m. of soluble aluminum were toxic and 71 p.p.m. not toxic. But inasmuch as manganese is much more toxic than aluminum, an acid manganiferous soil, and these are common in Kentucky, is more likely to contain a toxic quantity of active manganese than of active aluminum.

Lime is effective in reverting manganese to an insoluble form, being the only chemical which lowered the content of filterable manganese considerably below that of the check soil, whereas sodium carbonate actually increased the quantity of filterable manganese above that of the check soil, despite the alkaline reaction. A part of this undoubtedly was colloidal. Table 7 shows that there was little or no filterable manganese in the soil to which either calcium carbonate or calcium hydroxide had been added. This indicates that in an alkaline soil containing manganese, in the presence of calcium, manganese may be a limiting factor in plant growth.

#### YIELD OF LETTUCE

Graph 2 shows the relative yields and Table 6 the actual yields. Plot 12, which received sufficient sodium carbonate to maintain an average pH of 8.1 gave the largest yield of lettuce and plot 13, with an average of pH, 7.9 was next. Phosphoric acid and a pH of 5.7 (plot 15), and sulfuric acid and a pH of 6.4 (plot 6), gave similar yields which were third. With limestone and average pH 7.8 and 7.4 respectively (plots 4 and 5), and sodium carbonate and a pH 8.8 (plot 11), the results were similar and came fourth. The highly acid soil was about equal to the checks in yield, whereas in the highly limed soil (plot  $3\text{Ca}_1$ ) lower yields were obtained during the second season. The results obtained in this work indicate that an alkaline



medium is best as long as no complications occur from alkalinity, such as, change of manganese, iron and phosphorus into unavailable forms. From the yields alone it seems that sodium carbonate is not likely to cause complications and it undoubtedly favors nitrification and nitrogen fixation to such an extent that yields are materially increased.

The largest yield on the acid side was obtained in the presence of manure, whereas sodium carbonate without manure increased the yield more than any other treatment.

Nitric acid was especially deleterious to lettuce. Evidently, altho lettuce requires an ample supply of nitrate nitrogen, it is very sensitive to an excess of nitrate. Fig. 7 shows the dwarfing effect of the presence of 200 p.p.m. of nitrate nitrogen, in soil to which nitric acid has been added and the beneficial effect of 100 p.p.m. caused by the stimulation of nitrification by sodium carbonate.

#### YIELD OF TOMATOES

Sodium carbonate added to maintain a soil reaction of pH 8.3-8.4 gave the largest average increase in the yield of tomatoes. Large vines with a medium set of fruit, and large fruit were produced. The set was not so good in proportion to the vines as in the sulfuric acid and phosphoric acid treated plots, nor was the early yield so large, yet the total yield was much larger. The lower clusters showed vegetative tendencies by putting forth leaves and suckers and some blossom drop appeared, but the fruits which did set were above the average size. The upper clusters set many fruits without showing much vegetative tendency. With sodium carbonate and a pH 7.3-8.0 the second largest average yield was produced whereas lime and a pH 7.0-8.1 and sulfuric acid and pH 6.0-6.2 were tied for third place. This indicates that alkalinity is much more favorable for tomatoes than acidity. Phosphoric acid produced a yield slightly above the checks. Sulfuric acid and a pH of 4.3-5.3 always reduced the yields.

The outstanding influence here as with lettuce was on the nitrate content of the soil. A large amount of nitrate was not

so deleterious to tomatoes as to lettuce. The yield on the soil containing about 250 p.p.m. of nitrate nitrogen was small, whereas average yields above the check yields were produced on the soil which at first contained 150 to 200 p.p.m. of nitrate nitrogen and then dropped to about 80-90 p.p.m.

The sodium-carbonate-treated soil at about pH 8.3, on which the largest yield was produced, had 80-90 p.p.m. of nitrate nitrogen initially and averaged about 40 p.p.m. The high-calcium treated soil contained a large amount of nitrate at all times but some other element, probably phosphorus, was lacking to such an extent that the yields were only about equal to those on the check plots.

In the acid soils phosphorus seemed plentiful but nitrate was lacking. In some plots an average of only 20 p.p.m. of nitrate nitrogen was present. Near the maturity of the tomato crop the sulfuric-acid-treated soil and the high-phosphoric-acid-treated soil without manure contained only about 5 p.p.m. of nitrate nitrogen. This indicates that the nitrate production was not sufficient to supply the heavy demand of the tomatoes. The large amount of filterable phosphorus in the acid soil undoubtedly accounts for the good setting and early yield of the tomatoes.

Besides the large quantity of nitrate and fair quantity of phosphate in the sodium-carbonate-treated soil it may be that sodium was able to take the place of potassium and cause a more rapid production of carbohydrates to balance the abundant supply of nitrogen.

Kraus and Kraybill (53) have demonstrated that a large yield of tomatoes is associated with an abundant supply of both nitrogen and carbohydrates.

#### NITRATE NITROGEN IN THE PLANT

The first attempts to obtain reliable data on the influence of soil reaction on the amount of nitrate maintained in plant tissues were discouraging as the findings were not consistent. At times an alkaline reaction seemed to favor a large nitrate content and again an acid reaction seemed best.

The first analyses were made of the upper leaves and suckers of tomato plants and of the leaves of lettuce, no attention being paid to the age of the suckers or leaves or to the percentage of veins. Some analyses were then made of tissues of different ages and of separate samples of veins. It was found that the age and percentage of veins affected the content of nitrate nitrogen; the younger the tissues the smaller the nitrate content; the greater the percentage of veins the greater the nitrate content. Thereafter care was taken to have the samples for analysis as uniform as possible with regard to these two factors. Table 9 shows that the nitrate content in the tissues decreased from the base of the plant to the tips. Growing tips from check plots contained about 125 p.p.m. of nitrate nitrogen in the green tissues, whereas petioles from the base of the plant contained about 2500 p.p.m.

Two conclusions may be drawn from the data obtained. First that a direct correlation exists between pH of the soil and the nitrate content maintained in the conducting portions of the plant, and second that the correlation between pH of the soil and the content of nitrate in the meristematic tissue is inverse. In other words, with alkaline soil a much larger nitrate content was maintained in the stems and veins of the plant than with acid soil; also there was a more rapid utilization of this nitrate in the growing tips, which brought about a smaller nitrate content in the growing points. This was especially true in the growing tips of tomato suckers, in which considerably more nitrate nitrogen was found with an acid reaction of the soil than with an alkaline reaction. However, in stem and petiole tissue from the same plants, the nitrate content with alkaline reaction of the soil was much larger than with acid reaction. An alkaline reaction, besides stimulating nitrification in the soil, evidently stimulated both the absorption of nitrate by the roots and its assimilation by the growing points. This resulted in extensive vegetative growth as noted in particular on the sodium-carbonate-treated plots. The limed plots were not so outstanding in these effects as the sodium-carbonate-treated plots. However, where organic matter was used with lime, very large vine growth resulted and nitrate content was larger.

As a rule, the addition of sulfuric and phosphoric acids had similar effects on nitrate nitrogen content of the conducting tissues. Phosphoric acid, however, caused a more rapid utilization of nitrate in meristematic tissue than did sulfuric acid. Nitric acid led to an unusually large nitrate content in the plant and did not behave as the other acids.

The amount of nitrate present in the main stem of a plant should be one of the best indications of the rapidity of absorption of nitrate from the soil. However, because the project required the recording of yields of tomato fruits, the main stem of the tomato plant could not be taken for analysis. Hence, in order to estimate the amount of nitrate in the main stem, without affecting the yield of fruit, the enlarged portion of mature petioles next to the stem was analyzed. In lettuce, the midribs from mature leaves were taken for the same purpose. The data obtained on nitrate content in these tissues were very definite and showed that roots absorb a much larger amount of nitrate from alkaline soil than from acid soil. This was evident in both tomato and lettuce. Graph 1 presents a picture of this effect.

#### TOTAL NITROGEN IN THE PLANT

The determinations of total nitrogen in the plant do not seem to have much significance in relation to the soil reaction. Even tho an alkaline reaction stimulates nitrate absorption, carbohydrate formation is so stimulated that the percentage of total nitrogen is not greatly increased. As a rule, however, an alkaline reaction seems to bring about a somewhat greater total percentage of nitrogen than was found in the plants on the checks or on the acid soil. This is especially true with lettuce.

Table 12 presents determinations of total nitrogen in the roots of lettuce, not included in the graphs. These analyses indicate that sodium carbonate increased the total nitrogen in the roots. Sulfuric acid always diminished the total nitrogen content, but phosphoric acid seemed to have a tendency to increase it.

#### PHOSPHATE PHOSPHORUS AND TOTAL PHOSPHORUS IN THE PLANT

The percentage of phosphate phosphorus in the plants growing in acid soil was always larger than in the check plants. As with nitrate nitrogen, there was a great difference in the amounts of phosphate in the different parts of the plant. Leaves from the tomatoes on the check plots contained about 150 p.p.m. while the enlarged portion of the petiole next to the main stem contained about 1000 p.p.m.

With an alkaline reaction the outstanding result was that on the limed soil the phosphate phosphorus content in the plant was less than that in the check plants. This indicates that lime makes phosphorus unavailable to the plant. It seems that the amount of phosphate phosphorus in the plant is a better measure of the availability of phosphorus in the soil than the amount extracted from the soil by the weak solvents now in use. Undoubtedly the amount of phosphate phosphorus carried up the stem of the plant from the roots is the best index of the availability of phosphorus in the soil. Evidently sodium carbonate was not so effective in locking up phosphorus as lime, since the plants in the sodium-carbonate-treated soil usually contained considerably more phosphate phosphorus than did those in the check plots. This was true in all the stem portions examined. In only one test did the lettuce leaves in the sodium-carbonate-treated soil have a smaller phosphate phosphorus content than those in the check plots. Graph 4 pictures the results on phosphate phosphorus.

One point in crop four of tomatoes should be noted here. From Table 15 it will be seen that on plots 1-16 the petioles contained, on an average, about 500 p.p.m. less phosphate than those on plots 17-33. Plots 17-33 received a heavy application of rotted manure just before setting the plants. A comparison may be made of plots 3 Ca<sub>1</sub> and 18 Ca<sub>1</sub>, which had lime added to a pH of about 8.5. The tomatoes on 3 Ca<sub>1</sub> contained only 534 p.p.m. of phosphate phosphorus in the enlarged petioles next to the stem, whereas those on 18 Ca<sub>1</sub> having an equal addition of lime but also receiving manure at the rate of 25 tons per



acre, contained 1212 p.p.m. On 18 Ca<sub>1</sub> there was a heavy yield of fruit and vigorous, green vines. On 3 Ca<sub>1</sub> the yield of fruit was light and the leaves were yellowish. In fact, the plants on 3 Ca<sub>1</sub> died very early, whereas those on 18 Ca<sub>1</sub> were green and productive for nearly a month longer. Fig 7 shows this contrast. This suggests caution in the use of lime.

If much lime is to be applied, there is danger in some soils, at least, of ill effects unless a large amount of manure or other organic matter is added. The organic matter stimulates both the production of nitrate and the liberation of phosphate to the plants even if lime is present. The organic matter also probably prevents the complete locking up of iron, aluminum, and manganese, but with an alkaline reaction there is no danger of these elements coming into "active toxicity". Even if the reaction is made quite alkaline, in the presence of organic matter, the plant can still take up phosphorus (plots 18 Ca<sub>1</sub>, 25 Na, and 26 Na were about pH 8.0-8.5 and yet tomato petioles on these plots contained 1200 to 1500 p.p.m. of phosphate), and at the same time azofication may take place.

The ratio of total phosphorus (Table 17) and phosphate phosphorus in the plant is almost constant; more nearly so than the ratio of total nitrogen and nitrate nitrogen. Total phosphorus was larger in lettuce leaves and roots in the acid soil than in those on the heavily limed soil, and larger than the checks in those on the sodium-carbonate plots.

Only the tomato fruit was analyzed for total phosphorus. Here the results were not very consistent. In three instances in the sulfuric-acid-treated soil, the fruit contained a smaller percentage of phosphorus than that on the check soil. The addition of phosphoric acid to the soil did not increase the phosphorous content in the fruit. Lime seems to have diminished the percentage of phosphorus in the fruit.

#### MANGANESE IN THE PLANT

The first determinations of manganese in the plants were so conclusive that it was not considered necessary to make as many as with nitrogen and phosphorus.

With the addition of enough sulfuric acid to the soil to give pH about 4.5, the percentage of manganese in the lettuce leaves was almost six times as large as the average in the leaves on the check plots and that in the tomato petioles about ten times as large as on the check plots. Phosphoric acid had almost as great an effect. Nitric acid was not so effective as the other two acids.

Sodium carbonate usually diminished the manganese content in the plant below that in the plants on the check plots. In the limed soil, the manganese content in the plants was generally less than in the plants on the check plots.

Evidently sodium carbonate did not lower the available manganese content below that needed, since the yields were largest where sodium carbonate was used. In fact, it appears that sodium carbonate may even have prevented a toxic effect from too much manganese. Tomato plants on the acid soil were always lighter in color than those on the alkaline soil except those on the nitric-acid-treated soil. The contrast in manganese content of the plants in the acid and alkaline soil suggests the theory that the large amount of manganese caused an excessive oxidation of the chlorophyll, impeding reduction of carbon dioxide and nitrate, causing a general blanching out of chlorophyll. This undoubtedly would hinder the synthesis of carbohydrates.

### CORRELATIONS

*Methods.* To show correlations in the results, block graphs 1 to 6 were made, which summarize and illustrate most of the data in Tables 3 to 14. The findings from plots given similar treatments were averaged, and the findings from all the check plots were averaged to determine the check level. This procedure may have obscured some differences, particularly those obtained by adding organic matter in the form of compost, but the most important of these will be treated in the discussion.

In order to show how the block graphs were made the yields of tomatoes may be taken. Only crops 2 and 3 were used, because crop 1 was ruined by nematodes. The average yield

from check plots 2, 16 and 32, in crop 2, and 2, 16, 23 and 32, in crop 3, was found to be 99 oz. per plant for crop 2, and 45 oz. per plant for crop 3. The plots included in pH range 4.5-5.4 with sulfuric acid were plots 13, 14, 28 and 29. The average yield from these plots for crop 2 was 83 oz. per plant, and for crop 3, 39 oz. per plant. The percent which each of these is of the check yield was found as follows:

$$\text{For crop 2, } \frac{83 \times 100}{99} = 84. \quad \text{For crop 3, } \frac{39 \times 100}{45} = 86\frac{2}{3}$$

The average percent of the check yield was then 85+. Heights of all other blocks were determined in a similar way. Expressing the results as percent of check level provided a common scale for all the variables.

By careful observation of the graphs it is possible to make an approximation of the actual simple correlations existing. The following system was adopted in order to permit comparisons:

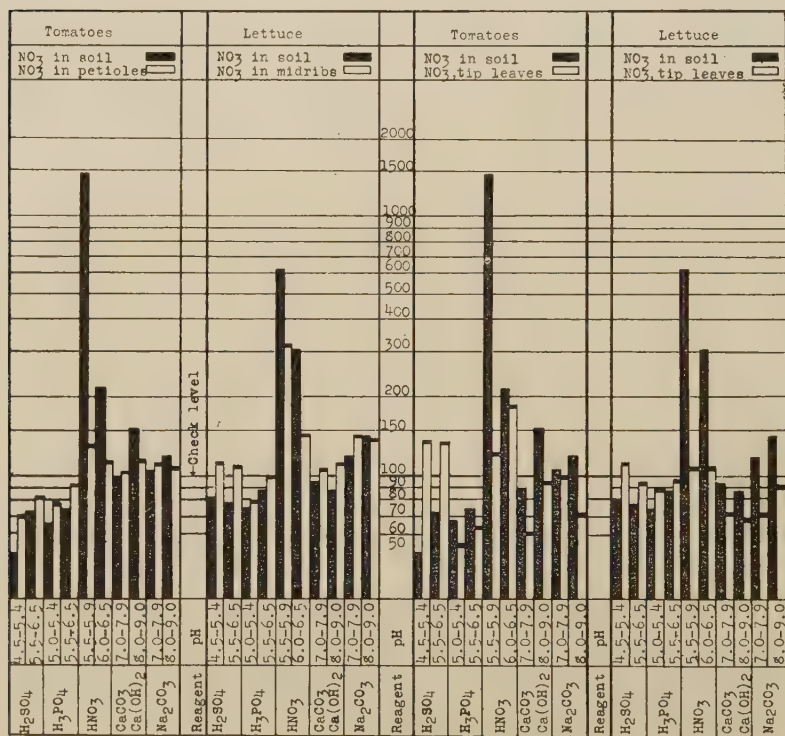
| Degree of Correlation |                                                  |
|-----------------------|--------------------------------------------------|
| Term Used             | Approximate Simple Correlation Coefficient Range |
| Excellent             | 0.80-0.89                                        |
| Good                  | 0.70-0.79                                        |
| Fair                  | 0.60-0.69                                        |
| Medium                | 0.50-0.59                                        |
| Poor                  | 0.40-0.49                                        |
| Not significant       | 0.10-0.39                                        |

This system is used in Tables 20 to 22 in comparing the correlations existing in the graphs.

*Nitrogen.* Graph 1 and Table 20 furnish conclusive proof that the amount of nitrate in the soil governs the amount of nitrate in the conducting tissues of both tomatoes and lettuce. It does not, however, control the amount of nitrate in meristematic tissues. In fact, the conditions conducive to a large nitrate

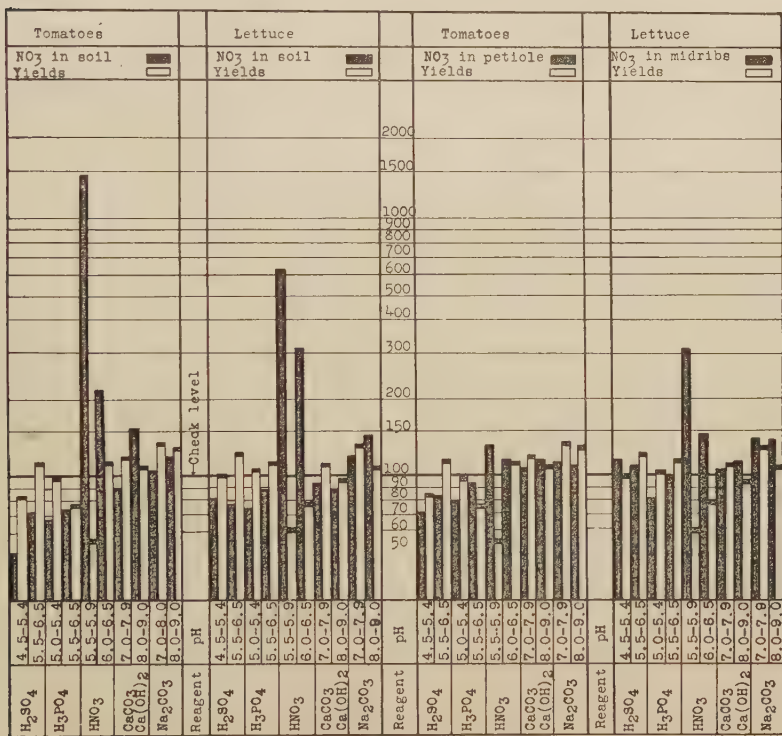
content in soil and conducting tissue seem to favor nitrate assimilation and protein synthesis in growing tissues to such an extent that inverse correlations exist between the nitrate content of the soil and of the meristem.

In graph 2 the correlations of nitrate nitrogen content in the soil and in the conducting tissue, with yields, are good for tomatoes, and fair for lettuce. This indicates that the amount of nitrate available is very important in tomato nutrition. In lettuce the nitrate content is important but other factors are evidently about as significant. In the correlations between nitrate content and yield the nitric-acid-treated soil was disregarded since it was evident that nitrate was present in toxic quantity.

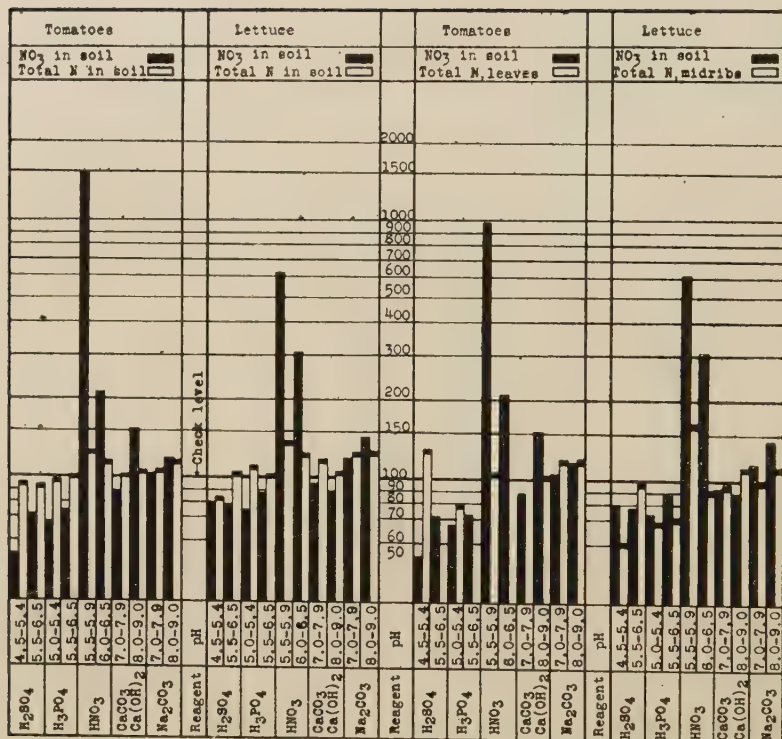


Graph 1. Relative Nitrate Content of Soil and of Plant.  
(Logarithmic Scale.)

Graph 3 and Table 20 indicate that conditions favoring rapid nitrification also favor rapid nonsymbiotic nitrogen fixation. The determinations of total nitrogen in tomato and lettuce tissues did not correlate well with anything, except that where an exceptionally large amount of nitrate existed in the soil, the total nitrogen in the tissues was increased considerably. The large amount of nitrate nitrogen present in the midribs of lettuce probably caused a fair correlation between nitrate nitrogen content of the soil and total nitrogen content of the midribs, rather than the amount of reduced nitrogen present.







Graph 3. Relative Nitrate Content and Total Nitrogen Content of Soil and Plant. (Logarithmic Scale.)

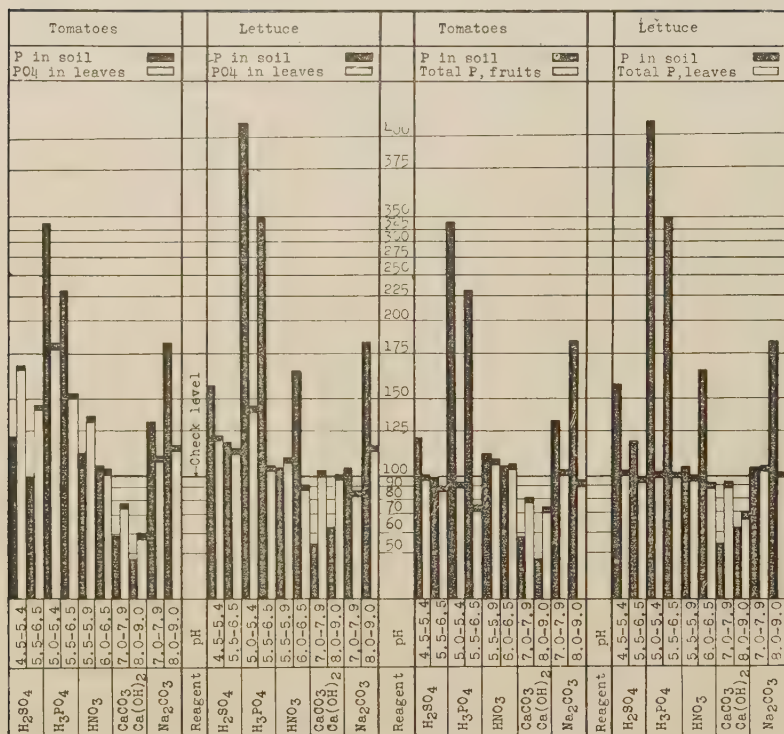
TABLE 20. Correlations Shown by Graphs 1, 2, and 3, Nitrogen Correlations. (The Term, Inverse, Designates a Minus Correlation Coefficient or Inverse Correlation.)

| Factors Correlated           |                                       | Correlation Existing |
|------------------------------|---------------------------------------|----------------------|
| Factor 1                     | Factor 2                              |                      |
| Nitrate N in soil            | Nitrate N in tomato petioles          | Excellent            |
| Nitrate N in soil            | Nitrate N in lettuce midribs          | Good                 |
| Nitrate N in soil            | Nitrate N in young leaves of tomatoes | Good inverse         |
| Nitrate N in soil            | Nitrate N in young leaves of lettuce  | Fair inverse         |
| Nitrate N in soil            | Tomato yields                         | Good                 |
| Nitrate N in Soil            | Lettuce yields                        | Fair                 |
| Nitrate N in tomato petioles | Tomato yields                         | Good                 |
| Nitrate N in lettuce midribs | Lettuce yields                        | Fair                 |
| Nitrate N in tomato soil     | Total N in tomato soil                | Excellent            |
| Nitrate N in lettuce soil    | Total N in lettuce soil               | Good                 |
| Nitrate N in soil            | Total N in tomato leaves              | Poor                 |
| Nitrate N in soil            | Total N in lettuce midribs            | Fair                 |

*Phosphorus.* That the amount of filterable phosphorus in the soil governed the amount of phosphate phosphorus in the plant is shown by Graph 4. On the lime-treated soil the phosphate phosphorus in the lettuce leaves was not so much smaller as would be expected from the results with tomato leaves nor so much larger in the sodium carbonate-treated soil of pH 7.0-7.9. Outside of this the correlations were excellent.

The filterable phosphorus content of the soil did not seem to have much significance in the tomato fruits. It seems strange that the large amount of phosphorus in the phosphoric-acid-treated soil did not increase the phosphorus content of the fruit.

The total phosphorus in lettuce leaves was influenced positively by the amount of filterable phosphorus in the soil, especially with an alkaline reaction.

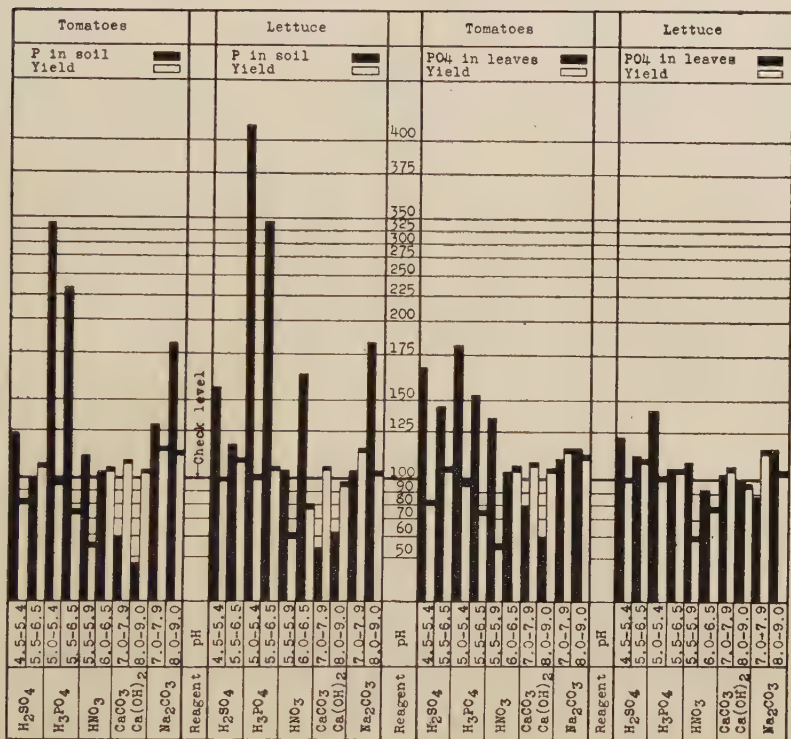


Graph 4. Relative Content of Filterable Phosphorus in the Soil Compared With the Relative Content of Phosphate Phosphorus and of Total Phosphorus in the Plant. (Logarithmic Scale.)

Graph 5 indicates that the abundance of filterable phosphorus in the soil favored an increase in yield but evidently other factors were equally important. The amount of phosphate phosphorus in the plant is a somewhat better indicator of growth than the amount of filterable phosphorus in the soil, altho the latter directly influences the amount in the plant. Evidently the small quantity of phosphate phosphorus in the plants on the calcium-treated soil caused a reduction in yield despite the fact that nitrate content was large. On the sodium-treated soil both phosphorus and nitrate were large and there was a consequent increase in yield.

With an acid reaction the percentage of filterable phos-

phorus in the soil was nearly always large, but here the nitrate content was the limiting factor, causing reduced yield.



Graph 5. Relative Content of Filterable Phosphorus in Soil, Phosphate Phosphorus in the Plant, and Relative Yield. (Logarithmic Scale.)

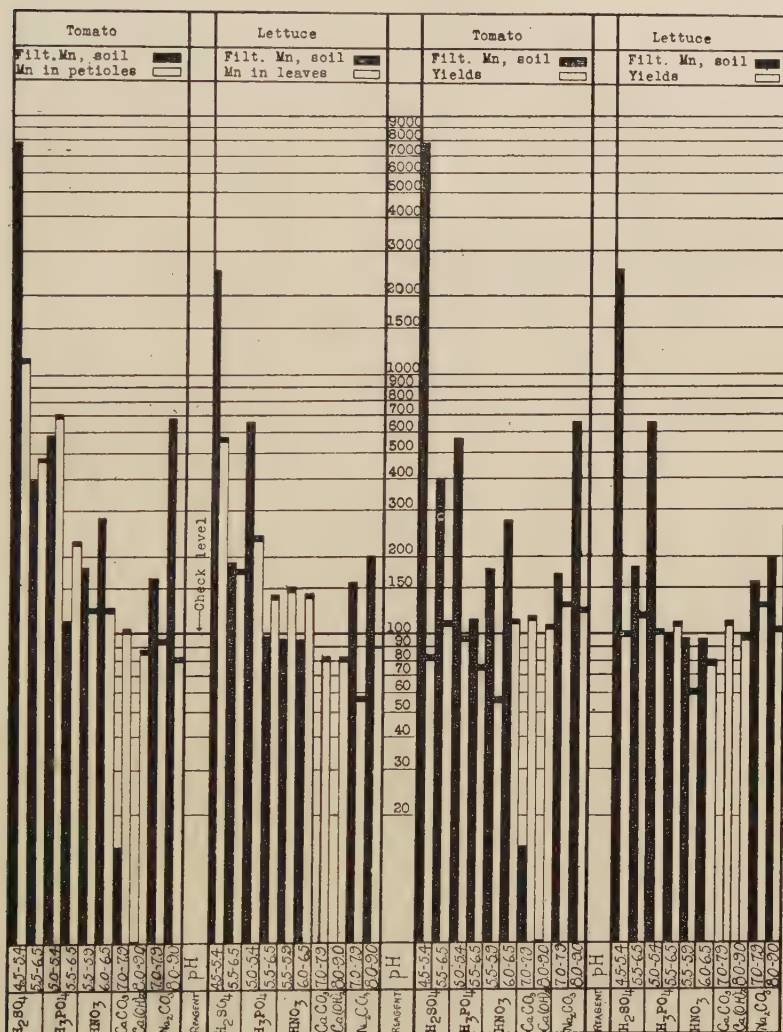
TABLE 21. Correlations Shown by Graphs 4 and 5, Phosphorus Correlations.

| Factors Correlated                   |                                      | Correlation Existing |
|--------------------------------------|--------------------------------------|----------------------|
| Factor 1                             | Factor 2                             |                      |
| Filterable P in soil                 | Phosphate P in mature tomato leaves  | Excellent            |
| Filterable P in soil                 | Phosphate P in mature lettuce leaves | Excellent            |
| Filterable P in soil                 | Total P in tomato fruits             | Fair                 |
| Filterable P in soil                 | Total P in lettuce leaves            | Good                 |
| Filterable P in soil                 | Tomato yields                        | Fair                 |
| Filterable P in soil                 | Lettuce yields                       | Fair                 |
| Phosphate P in mature tomato leaves  | Tomato yields                        | Good                 |
| Phosphate P in mature lettuce leaves | Lettuce yields                       | Fair                 |

*Manganese.* The great increase in the proportion of filterable manganese in the soil with an acid reaction was roughly proportional to an increase in the manganese content of the plant. Likewise the decrease in the calcium-treated soils decreased the amount in the plant. In the sodium-treated soils, however, the increase in filterable manganese in the soil did not increase the amount in the plant as much as would be expected.

The correlation between the amounts of filterable manganese in the soil and the yields of lettuce and tomatoes was nearly always inverse. It seems that the supply of manganese seldom became so low that it became a limiting factor, while the amount of filterable manganese easily reached toxic limits. The only case where manganese may have been limiting seems to be in the calcium-treated soil where the proportion of filterable phosphorus, also, was small. It was impossible to distinguish whether phosphorus or manganese or both might have been limiting factors in these treatments.





Graph 6. Relative Content of Filterable Manganese in Soil, Total Manganese in the Plant, and Relative Yield. (Logarithmic Scale.)

TABLE 22. Correlations shown by Graph 6, Manganese Correlations. (The Term, Inverse, Designates a Minus Correlation Coefficient or Inverse Correlation.)

| Factors Correlated    |                         | Correlation Existing |
|-----------------------|-------------------------|----------------------|
| Factor 1              | Factor 2                |                      |
| Filterable Mn in soil | In petioles of tomatoes | Good                 |
| Filterable Mn in soil | In lettuce leaves       | Excellent            |
| Filterable Mn in soil | Tomato yields           | Good inverse         |
| Filterable Mn in soil | Lettuce yields          | Fair inverse         |

#### OTHER EFFECTS OF CONTROLLED SOIL REACTION

*Color and Other Physical Properties of the Soil.* The acids added did not seem to change the color or physical properties of the soil materially. The color of very acid soil became a trifle lighter. The acids undoubtedly caused precipitation of colloidal material, since the acidified soil gave clearer filtrates than the checks. Phosphoric acid often caused a slight whitish appearance on the surface which looked like some sort of salt. It was plain that nitric acid acted on organic matter since some foaming and evolution of gas took place despite the fact that the acid was greatly diluted before being added.

Lime gave a slightly darker color to the soil and a loose texture. The filtrates from the limed soil were nearly as clear as those from the acid soil.

Sodium carbonate caused an extremely dark color, and at first a rather pasty, puddled condition. In about a month, however, this puddled condition seemed to be greatly reduced and in six months the tilth of the sodium-carbonate-treated soil was about as good as that of the calcium-carbonate treated-plots, altho a darker color persisted.

The great difference between sodium and calcium-treated soil was that the sodium-treated soil retained water much longer than the limed soil. This was an advantage in the greenhouse benches since the soil dried out rapidly. The acid soil seemed to dry out faster than either the checks or the alkaline soil.

The filtrate from the sodium-carbonate-treated soil con-

tained much colloidal matter, was very dark in color, and passed thru the filter very slowly. Evidently much colloidal material was formed. Much of this probably was in the form of the insoluble hydroxides of manganese, iron, and aluminum, altho organic colloids were undoubtedly present, since much organic matter watter was brought into solution.

*Color of the Plants.* The tomato plants on the acid soil were a considerably lighter green and those on the alkaline soil a darker green than those on the check plots. The plants on the nitric-acid-treated soil were an exception in that they were a darker green than those on any of the other plots. They also made a more spindling growth and harder wood. This was not true after the large nitrate content was leached out, since the fourth crop developed a large growth of succulent vines of a color similar to those grown on the sodium-carbonate-treated soil. The light color of the plants on soil with an acid reaction presumably was due to some inhibiting effect on chlorophyll formation. This has already been referred to.

At one time a distinct blanching out of the veins occurred in the plants on the soil to which much sulfuric has been added. The effect was almost exactly like that described by Jacobson and Swanback (47) on tobacco. This soil contained a large amount of filterable manganese as compared with the other soils. (See Table 18.) The plants on the phosphoric-acid-treated soil were not so light in color as those on the sulfuric-acid-treated soil.

*Curling of Leaves.* Observation indicated that the leaves of the tomato plants curled most on those plots where the nitrate content was large, namely, the nitric-acid-treated and alkaline soil. The effect, however, was not very definite since curling appeared at times in other plots.

*Evenness of Growth.* Only on soil to which a large amount of acid had been applied did the plants show much unevenness in growth. On one corner of a strongly acid plot the plants sometimes would be stunted while at an opposite corner they would grow normally. The pH in the soil differed in the different parts of the plots but not more than several tenths of a unit, which would hardly account for the differences in plant

growth. It must have been that in applying the acids, the soil in some parts of the plot was acted on more vigorously than in others, before water was applied to distribute the acid throughout the soil mass. In the portions where much action occurred some toxic element (e. g. manganese) probably was dissolved to a greater extent than in the other portions. After the water was applied the acid was fairly well distributed, but a higher concentration of the toxic element may have been maintained in a particular spot.

*Blossom Drop.* Some data were taken on blossom drop, but were not very consistent. They seemed to suggest that phosphoric acid enhanced the set of blossoms, whereas lime caused a dropping of blossoms.

*Nematodes.* From casual observations it seemed that the extremes of acidity and alkalinity retarded nematode development and that sodium carbonate might prove beneficial in this respect.

*Fusarium Wilt.* *Fusarium* wilt often occurred in crop 1, but never was found in the sodium-carbonate-treated soil, even when it was present in the next plot. Lime was not so effective, since wilt was occasionally found in the limed plots. Nitric acid seemed to favor the development of wilt, and it occurred in the other acid plots more often than in the checks. The use of Marglobe plants in the second and third crops almost entirely overcame the difficulty with wilt.

### CONCLUSIONS

The following conclusions may be drawn from the results obtained in this investigation:

#### pH Values

1. To maintain a constant pH value in a soil in which plants are growing, by the addition of chemical reagents, is not practicable. The extremes, pH 4 and pH 9, were the most difficult to maintain. A range of 0.5 pH on either side of the desired pH was deemed close enough for this investigation.

2. A more nearly constant pH was maintained with sulfuric acid than with either phosphoric or nitric acid, and with

either calcium hydroxide or calcium carbonate than with sodium carbonate.

3. The variations in pH were largely due to action of the plants, to leaching from a raised bench, and to chemical reactions and adsorption between the added substance and the components of the soil.

4. The pH of the check plot soils changed toward alkalinity as the experiment progressed.

#### **Yields of Tomato Fruit**

1. Sodium carbonate added to maintain a pH of about 8.3-8.4 gave the largest yield of tomatoes. The second largest yield of tomatoes, was produced with sodium carbonate, at pH 7.3-8.0. Foliage growth was luxuriant on the sodium-carbonate-treated soil.

2. The third largest yield of tomatoes was produced by both lime at pH 7.0-8.1 and sulfuric acid at pH 6.0-6.2.

3. Phosphoric acid produced increases over check plots in practically every case, while sulfuric acid at pH 4.3-5.3 always reduced the yields.

4. Good setting and large early yields occurred with an acid reaction, but the vines soon yellowed and the total yield was small, whereas plants on the alkaline plots remained green and continued to yield for a long time.

5. Much lime without manure (plot 3Ca) caused a yellowing of the plant and low yield. On heavily limed plot (18 Ca<sub>1</sub>) with manure, a green, vigorous vine growth occurred, with an excellent set of tomatoes.

#### **Yields of Lettuce**

1. The plot receiving sodium carbonate to maintain a pH of about 7.5 gave the largest yield. A large, succulent growth of leaf lettuce resulted. No stunting occurred such as was observed on some of the heavily limed and acid plots.

2. With sodium carbonate and pH 8.5 there was some stunting, especially in the later crops.

3. With phosphoric acid and pH 6.5, and sulfuric acid and pH 6.8, the second largest yields were obtained.



4. With lime and pH 7.2 and with sodium carbonate and a pH 8.5 the third largest yields were obtained.

5. Manure was necessary when the reaction was acid in order to permit a large yield, while sodium carbonate alone was sufficient with an alkaline reaction to give large yields.

6. Addition of nitric acid was injurious to lettuce.

#### **Nitrification**

1. The largest content of nitrate in the soil to which none was added, was maintained in the plot that received sodium carbonate. Soil that received much calcium hydroxide or calcium carbonate had a large nitrate content, but soil that received a small amount of calcium carbonate sometimes had less than the controls.

2. The nitrate content in soil having an acid reaction usually was less than that in the checks, the smallest amount occurring in the sulfuric-acid-treated soil.

3. High nitrate content of the soil with an alkaline reaction undoubtedly was a large factor in increasing the yields of tomatoes and lettuce. This shows the importance of making conditions favorable to rapid nitrification.

4. It is suggested that addition of a small amount of sodium carbonate and a large amount of organic matter (not necessarily high in nitrogen) would be a good way to stimulate nitrate production in poor soils.

#### **Nonsymbiotic Fixation of Nitrogen**

1. The total nitrogen content of the soil varied much the same as did the nitrate content. With sodium carbonate and pH 7.6, the increase in total nitrogen was equivalent to as much as 1000 pounds per acre. This undoubtedly was due to vigorous stimulation of nonsymbiotic nitrogen fixation, or azofication.

2. In the calcium-treated soil azofication increased at first, but with time a depression occurred. It is suggested that both nitrification and azofication were limited by the small amount of filterable phosphorus in the calcium-treated soil.

3. The necessity for the presence of organic matter as energy material was evident.

4. It is suggested that application of a small amount of

sodium carbonate, a medium amount of lime (to enhance tilth) and a large amount of crop residues would be a cheap and efficient way to maintain the nitrogen supply in the soil by promoting azofication. A pH of about 7.5 seems to be necessary to attain both optimum nitrification and optimum azofication.

5. No significant increase in total nitrogen content occurred in acid soil and, in some instances, it was diminished.

#### **Transformations of Phosphorus Compounds**

1. The content of filterable phosphorus in the soil was increased with an acid reaction in the range of about pH 4.5-5.5, but between pH 5.5 and pH 7.0 it was sometimes decreased.

2. Soil treated with much lime always had a small content of filterable phosphorus.

3. Sodium carbonate caused a rather large increase in the content of filterable phosphorus of the soil. This resulted in a larger phosphate content in the plants and increased yields.

4. Addition of manure greatly increased the phosphate phosphorous content of the plant. This was evident on the heavily limed plots and likely explains the much better growth on the manured and limed plots than on those that received lime only.

#### **Transformations of Manganese Compounds**

1. Acidity greatly increased the content of filterable manganese, whereas alkalinity depressed it.

2. Because a very small quantity of manganese is toxic to plants, it is suggested that manganese may be a common cause of growth retardation in acid soils. Since lime is very efficient in changing manganese to an insoluble form it is possible that the beneficial effects of lime are greater in precipitating manganese than in actually neutralizing acidity.

3. Sodium carbonate increased the content of filterable manganese slightly, but did not cause a corresponding increase in the content of manganese in the plant.

#### **Nitrate Nitrogen in the Plant**

1. The age of the tissue analyzed and the percentage of veins must be considered in making nitrate determinations in plant tissues.

2. The nitrate content of the tissues decreased from the base to the tips of the plant.

3. An alkaline reaction in the soil maintained the largest nitrate content in the stems and veins of the plant, but it stimulated the rapid utilization of the nitrate in the growing tips, which resulted in a smaller nitrate content in the meristem than was maintained with the acid soil. Sodium carbonate was most outstanding in this effect. When organic matter was added with lime the effect was nearly equal to that of sodium carbonate alone.

4. Both sulfuric and phosphoric acids reduced the nitrate content of the conducting tissues of the plant, but phosphoric acid caused a more rapid utilization of nitrate in the meristematic tissues than did sulfuric acid.

5. The content of plant food in the conducting tissues of plants grown in a soil probably was a better index of the availability of nutrients in the soil than the content of the soil itself.

#### **Total Nitrogen in the Plant**

1. An alkaline reaction in the soil seemed to increase the percentage of total nitrogen somewhat, but the results were not significant.

2. A large total nitrogen content did not seem to be essential for large yields of tomato fruit, but did seem to favor foliage growth in lettuce.

#### **Phosphate Phosphorus and Total Phosphorus in the Plant**

1. With an acid reaction a high phosphate phosphorus content was maintained in the plant, but the nitrate content was low and evidently was a limiting factor, since only the early yields were increased.

2. The conducting tissues contained a larger proportion of phosphate phosphorus than the leaves.

3. Addition of lime to the soil caused an exceptionally low phosphate phosphorus content in the plant.

4. When much organic matter was added with lime, the phosphate content of the plant was increased and phosphorus probably was not so much a limiting factor as on the plots low in organic matter.

5. Addition of sodium carbonate usually caused an increase over that in the plants on the checks, indicating that phosphorus was not locked up by this treatment.

6. The proportion of phosphate in the conducting system of the plant was a good index of the availability of phosphorus in the soil.

7. The total phosphorus content of tomato leaves varied with the phosphate phosphorus content of the soil, being high at a strongly acid reaction, low in the limed soil, and medium in the sodium carbonate-treated soil.

8. The total phosphorous content in tomato fruit was not very consistent. Lime applied to the soil decreased it somewhat, while phosphoric acid did not increase it.

#### **Manganese in the Plant**

1. On soil treated with sulfuric acid, the leaves of lettuce contained about six times as much manganese as on the check plots, and the petioles of tomato plants about ten times as much.

2. With an alkaline reaction the manganese content of the plants was less than that of the plants on the checks, in most instances.

3. Evidently, with an acid reaction, enough manganese was dissolved to be toxic, blanching out the chlorophyll and giving a lighter color of foliage along with a smaller total yield.

#### **Correlations**

Tables 20, 21 and 22 show the correlations between the factors involved in the results presented in Tables 1 to 19, obtained from the block graphs.

The excellent correlations of nitrate nitrogen, filterable phosphorus, and filterable manganese in the soil with nitrate nitrogen, phosphate phosphorus, and manganese in the plant justify the conclusion previously drawn that the amounts of nutrients in the conducting tissues of the plant are as good an indication of the fertility of the soil as determinations in the soil itself.

The correlation between phosphate phosphorus content of the plant and yield indicates that determination of phosphate

in the plant is of more value than determination of available phosphorus in the soil.

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Fig. 1. Manure increased the yield of lettuce somewhat, but the addition of sodium carbonate to cause an average pH of 7.6 produced the largest yield of any treatment. The average yields for five crops of lettuce were: Plot 2, 2.91; Plot 10, 4.36; Plot 12, 5.19 ozs. per plant.



Fig. 2. Comparative effect of the alkalis. The average yields were: Plot 5, 4.82; Plot 12, 5.19; Plot 3, 3.80 ozs. per plant.



Fig. 3. Stimulating action of a small amount of acid, and of sodium carbonate. The carbonate caused the greatest stimulation. Average yields were: Plot 6, 4.67; Plot 2, 2.91; Plot 12, 5.19 ozs. per plant.



Fig. 4. In crop 4, the one photographed, the phosphoric acid plots gave the largest yields, in the acid range, but in the average of five crops, the yield from the sulfuric acid plots was the largest by 0.12 oz. Average yields were: Plot 15, 4.44; Plot 7, 4.56; Plot 9, 2.30 ozs. per plant.



Fig. 5. Sodium carbonate, even in small quantity, caused marked stimulation of lettuce. Nitric acid in small quantity caused a marked depression in growth. Average yields were: Plot 19, 3.07; Plot 7, 4.56; Plot 13, 4.76 ozs. per plant.



Fig. 6.

|                                 | 8 Ca                                          | 20 Ca                                         |
|---------------------------------|-----------------------------------------------|-----------------------------------------------|
| Chemicals added, grams .....    | 2200 $\text{CaCO}_3$<br>500 $\text{Ca(OH)}_2$ | 8300 $\text{CaCO}_3$<br>500 $\text{Ca(OH)}_2$ |
| Compost added, tons per A. .... | None                                          | 25.                                           |
| Av. reaction of soil .....      | 7.17                                          | 7.63                                          |
| Av. yields (crop 3), ozs. ....  | 52.30                                         | 50.80                                         |

Altho the yields were about the same, 20 Ca with compost had a somewhat more vigorous vine growth. Evidently the calcium at this reaction was not harmful, even in the absence of organic matter, since the yields were greater than on the check plots (see Fig. 10).



Fig. 7.

|                                    | 3 Ca                          | 18 Ca                         |
|------------------------------------|-------------------------------|-------------------------------|
| Chemicals added, grams .....       | 2500 $\text{Ca}(\text{OH})_2$ | 2500 $\text{Ca}(\text{OH})_2$ |
| Compost added, in tons per A. .... | None                          | 25.                           |
| Av. reaction of soil .....         | 8.39                          | 8.35                          |
| Av. yields (crop 3) .....          | 29.00                         | 65.70                         |

Addition of compost caused much more vigorous growth and large green vines. The plants on the plot without compost were yellowish. Considerable blossom drop was noted. Lime without organic matter evidently was harmful.



Fig. 8.

|                                 | 11 Na                        | 27 Na                        |
|---------------------------------|------------------------------|------------------------------|
| Chemicals added, grams .....    | 100 $\text{Na}_2\text{CO}_3$ | 100 $\text{Na}_2\text{CO}_3$ |
| Compost added, tons per A. .... | None                         | 25.                          |
| Av. reaction of soil .....      | 7.43                         | 7.35                         |
| Av. yields (crop 3) .....       | 50.20                        | 62.80                        |

The organic matter in 27 Na undoubtedly effected more vigorous nitrate production, as evidenced in the large, dark green growth, and increased yield.





Fig. 9.

|                                 | 26 Na                        | 10 Na                        |
|---------------------------------|------------------------------|------------------------------|
| Chemicals added, grams .....    | 350 $\text{Na}_2\text{CO}_3$ | 300 $\text{Na}_2\text{CO}_3$ |
| Compost added, tons per A. .... | 25.                          | None                         |
| Av. reaction of soil .....      | 7.70                         | 7.84                         |
| Av. yields (crop 3) .....       | 57.50                        | 51.80                        |

Here again the solution of organic matter in 26 Na by sodium carbonate in the soil caused a more vigorous vine growth, but not so great as in 18 Ca (see Fig. 7).



Fig. 10.

|                                 | 32 Ck | 2 Ck  |
|---------------------------------|-------|-------|
| Chemicals added .....           | None  | None  |
| Compost added, tons per A. .... | 25.   | None  |
| Av. reaction of soil .....      | 6.91  | 6.80  |
| Av. yields (crop 3) .....       | 45.00 | 38.30 |

The presence of organic matter in 32 Ck undoubtedly was responsible for the greatly increased vine growth and yield of fruit.





Fig. 11.

|                                 | 29 S                         | 13 S                         |
|---------------------------------|------------------------------|------------------------------|
| Chemicals added, grams .....    | 1100 $\text{H}_2\text{SO}_4$ | 1300 $\text{H}_2\text{SO}_4$ |
| Compost added, tons per A. .... | 25.                          | None                         |
| Av. reaction obtained .....     | 5.24                         | 5.22                         |
| Av. yields (crop 3) .....       | 34.50                        | 37.00                        |

The addition of organic matter to an acid soil did not increase the yield. The foliage growth, altho somewhat greater in 29S, was not so greatly different. Note that the yield of 29S was 34.5 oz. per plant while 18 Ca (see Fig. 7) was 65.7 oz. per plant.

